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Back to the egg

Part II: An evidence-based endodontic implant algorithm

By Kenneth S. Serota, DDS, MMSc

"The laws of nature are but the mathematical thoughts of God ..."
— Euclid

Four thousand years ago, a number of Babylonian legal decisions were compiled in what came to be known as the Code of Hammurabi.

The one referencing the construction of dwellings and the responsibility for their safety begins: if a builder engineers a house for a man and does not make it firm, and the structure collapses and causes the death of the owner, the builder shall be put to death.

We are all builders or engineers of sorts; we calculate the path of our arms and legs with the computer of our brain, and we catch baseballs and footballs with greater dependability than the most advanced weapons system intercepts missiles. In our professional lives, however, in contradistinction to the paradigm of evidence-based dentistry, our efforts as builders often rely solely upon personal experience, intuitive cognition and anecdotal accounts of successful strategies.

The challenges posed by implant-driven treatment planning mandate vigilance of the interaction between those involved in research and development, manufacturing and distribution and the leaders of ideologically diverse disciplines. Temporal shifts and trends in the service mix are part of the evolution of the art and science of dentistry; to some degree, the implant-driven vector has captured the heart and minds of those who seek to nullify preservation of natural tooth structure in the oral ecosystem and deify orthobiologic replacement. The corporate entities from which we derive our tools too often fail to distinguish the point where science ends and policy begins.

By positioning advocates and acolytes at the vanguard of their marketing campaigns, they effect change; however, their support for education is directed toward dissemination of product, not the fundamentals and rudiments of biologic imperatives. Prospective large cohort clinical trials with clearly defined criteria for survival, with and without intervention, quality of life information and economic outcomes, are essential to compare alternative foundational treatments. These studies will require expertise, time and financial support from the various stakeholders, professional and corporate alike[1].

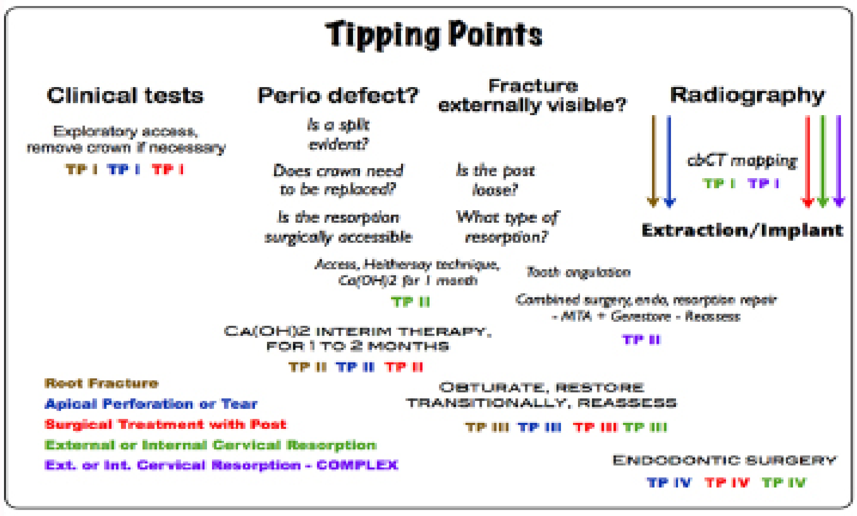

Fig. 1: The term tipping point refers to the moment of critical mass, the threshold, the boiling point. The color sequence highlights the diagnostic steps to be followed in each tipping point algorithm for the listed pathologic states. (Photos/Provided by Dr. Kenneth Serota)

"The authority of those who teach is often an obstacle to those who want to learn." — Cicero

The prosthodontic pundits maintain that the spiraling costs of saving endodontically retreated teeth, where extraction may well prove to be the common endpoint, begs the question of whether such teeth should be sacrificed early. Ruskin et al concluded that implants have greater success than endodontic therapy, are more predictable and cost less when you consider the "inevitable" failure of initial root canal treatment, retreatment and periapical surgery.[2] Is it responsible therapeutics or irresponsible expediency that justifies the removal and restoration of such teeth from the outset with an implant-supported restoration? Can one ethically argue that extraction is warranted as the financial cost of orthodontic extrusion/soft tissue surgery, endodontic retreatment and post/core/crown fabrication is greater than extraction with an implant-buttressed restoration, and in all likelihood, more predictable[3]?

Jokstad et al[4] identified more than 220 implant brands in the dental marketplace. With variability in surface, shape, length, width and form, there are potentially more than 2,000 implants for any given treatment situation. A systematic review by Berglundh et al[5] assessed the reporting of biologic and technical complications in prospective implant studies. Their findings indicated that while implant survival and loss were reported in all studies, biologic difficulties such as sensory disturbance, soft-tissue complications, peri-implantitis/mucositis and crestal bone loss were considered in only 40 to 60 percent of studies.

Technical complications such as component/connection and superstructure failure were addressed in only 60 to 80 percent of the studies. Are we as a profession standing idly by and watching marketing pressures force treatment decisions to be made empirically, with untested materials and techniques? There is an unsettling similarity between these events and the early days of implant development[6].

The endodontic pundits argue major studies published to date suggest there is no difference in long-term prognosis between single-tooth implants and restored root canal-treated teeth. In fact, regardless of the similarity of treatment outcomes, the preponderance of post-treatment complications favors endodontic ther-

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Tactile perception in endodontics

By Barry Lee Musikant, DMD

When it comes to tactile perception, most dentists doing root-canal therapy would agree more is better. But what exactly do we mean when we talk about tactile perception? To me, tactile perception is how accurate we can be in determining what the tip of the negotiating endodontic instrument is encountering. Is it encountering an impediment such as a solid wall or is it lodged in a tight canal? Is the tip of the instrument entering a round or oval canal?

Superior tactile perception is a direct result of the instruments design and how it is used. A reasonable analytic task is to determine what endodontic instrument designs and techniques enhance tactile perception. For sure, the information conveyed from the tip of the instrument will become increasingly clear as the engagement along length is reduced. If there is a great deal of engagement along length, exactly what the tip of the instrument is encountering becomes murky.

In that light the typical K-file design consisting of 30 horizontally oriented flutes along length (Fig. 1) will engage the walls of the canal significantly more than a reamer with 16 more vertically oriented flutes (Fig. 2).

If both the reamer and the file are made from a square wire, the reamer with 16 flutes will have a

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Fig. 1

Fig. 2

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apy. Therefore, the decision to treat a tooth endodontically or to place a single-tooth implant should be based on criteria such as restorability of the tooth, quality and quantity of bone, esthetic demands, cost-benefit ratio, systemic factors, potential for adverse effects and patient preferences.[7-11] A review of endodontic treatment outcomes by Friedman and Mor[12] used radiographic absence of disease and clinical absence of signs and symptoms as the defining parameters for success. They suggested the chance of having a tooth extracted after failure from initial endodontic treatment, retreatment and apical surgery collectively would be roughly one in 500 cases.

The dialogue comparing "endodontic treatment vs. implant therapy" jarringly overlooks the crucial fact that it is often the caliber of the restoration and its prognosis and not the endodontic prognosis per se, that is the determinant of the treatment outcome. The primary biologic mandate of any dental procedure is the retention of the orofacial ecosystem in a disease-free state. Surgical and nonsurgical endodontic therapies have historically been key modalities in the attainment of this foundational goal. Friedman noted "the patient weighing one 'success' rate against the other may erroneously assume their definitions to be comparable and select the treatment alternative that appears to be offering the better chance of 'success.' "[15] The conundrum researchers and clinicians alike wrestle with increasingly includes the non-science of emotion as well.

This publication will address nonsurgical and/or surgical resolution of failing primary endodontic treatment outcomes and the historic and ongoing efforts of the dental industry to successfully engineer the biomimetic replacement of natural teeth and replicate the structural predicates that comprise the substitution algorithm of bone, soft tissue and tooth. There are many levels to the accrual of "best evidence dentistry." The purpose of this paper is to ensure all variables in the treatment-planning equation of foundational dentistry are understood and given equal weight in the comprehensive care decision-making process.

Whenever possible, the treatment choice should be an attempt to salvage a tooth using a multidisciplinary team approach, putting aside preconceived notions and biases. Finances should not dictate the advice proffered. Furthermore, it is advisable to forego being clinically "conservative." Treatment should not be initiated in the absence of a critical evaluation of the potential for all contributing factors to equate with a positive outcome. When needed, care must be taken to carry out every diagnostic procedure available, even those of a more invasive nature (Fig. 1). Before arriving at a definitive diagnosis and treatment plan, the clinician should obtain consent from the patient to remove any restoration in order to analyze the residual tooth structure and assess the potential to carry out reliably predictable treatment. The patient must understand in detail the feasibility of and margin for success of each treatment option presented.[14]

Size	Success
0 mm	87.6%
1 – 5 mm	65.7%
+ 5 mm	56.2%

Table I: As reported by Chugal et al, the most significant vector impacting postoperative healing is the presence and magnitude of preoperative apical periodontitis.

Fig. 2a: The use of dyes, coloring agents and micro-etching is invaluable in visualizing a suspected crack in tooth structure. Cohen et al found when premolars were used as bridge abutments, a surprising number of these abutments sustained a VRF. [J Am Dent Assoc 2003; 134(4)434-441].

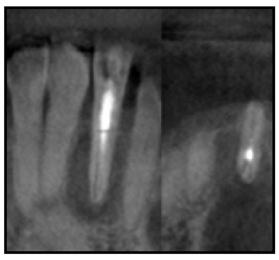

Fig. 2b: The dental literature reports a statistically higher level of accuracy using cbCT (cone beam volumetric tomography) scans for detecting vertical root fractures than with the use of periapical radiography alone.

Fig. 2c: The multivariate nature of the endodontic implant algorithm mandates the use of cbCT to detect and evaluate the degree of periapical pathosis. Analysis of the size, extent, nature and position of periapical and resorptive lesions in three dimensions is essential for the optimal level of standard of care in diagnosis.

There are few studies in the endodontic literature analyzing the reasons for extraction of endodontically treated teeth. Root-filled teeth are invariably prone to extraction due to non-restorable carious destruction and fracture of unprotected cusps. Tamse et al found that mandibular first molars were extracted with greater frequency than maxillary first molars; the most significant causal difference was the incidence of vertical root fracture (VRF — 1.8 percent maxillary molar, 9.8 percent mandibular molar).[15] Teeth not crowned after obturation are lost with six times the frequency of those restored with full coverage restorations.[16]

Procedural failure, iatrogenic perforation or stripping, idiopathic resorption, trauma and periodontal disease all contribute to a lesser degree. The major biologic factor influencing endodontic treatment outcome failure with the possibility of extraction appears to be the extent of microbiological insult to the pulp and periapical tissue, as reflected by the periapical diagnosis and the magnitude of periapical pathosis[17] (Table I) (Figs. 2a, 2b, 2c).

Dentin is the most abundant mineralized tissue in the human tooth. In spite of this importance, over half a century of research has failed to provide consistent values of dentin's mechanical properties. In clinical dentistry, knowledge of these properties is pivotal to any number of variables ranging from innovations in preparation design to the choice of bonding materials and methods. The Young's modulus (the measure of the stiffness of an isotropic elastic material) and the shear modulus (modulus of rigidity) are diminished by visco-elastic behaviour (time-dependent stress relaxation) at strain rates of physiologic (functional) relevance. The reported tensile strength data suggests that failure initiates at flaws. These flaws may be intrinsic, perhaps regions of altered mineralization, or extrinsic, caused by cavity or post channel preparation, wear or damage. There have been few studies of fracture toughness or fatigue.[18] Finally, little is known about the biomechanical properties of altered forms of dentin subsequent to decay, the influence of irrigants,

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ET Corrections

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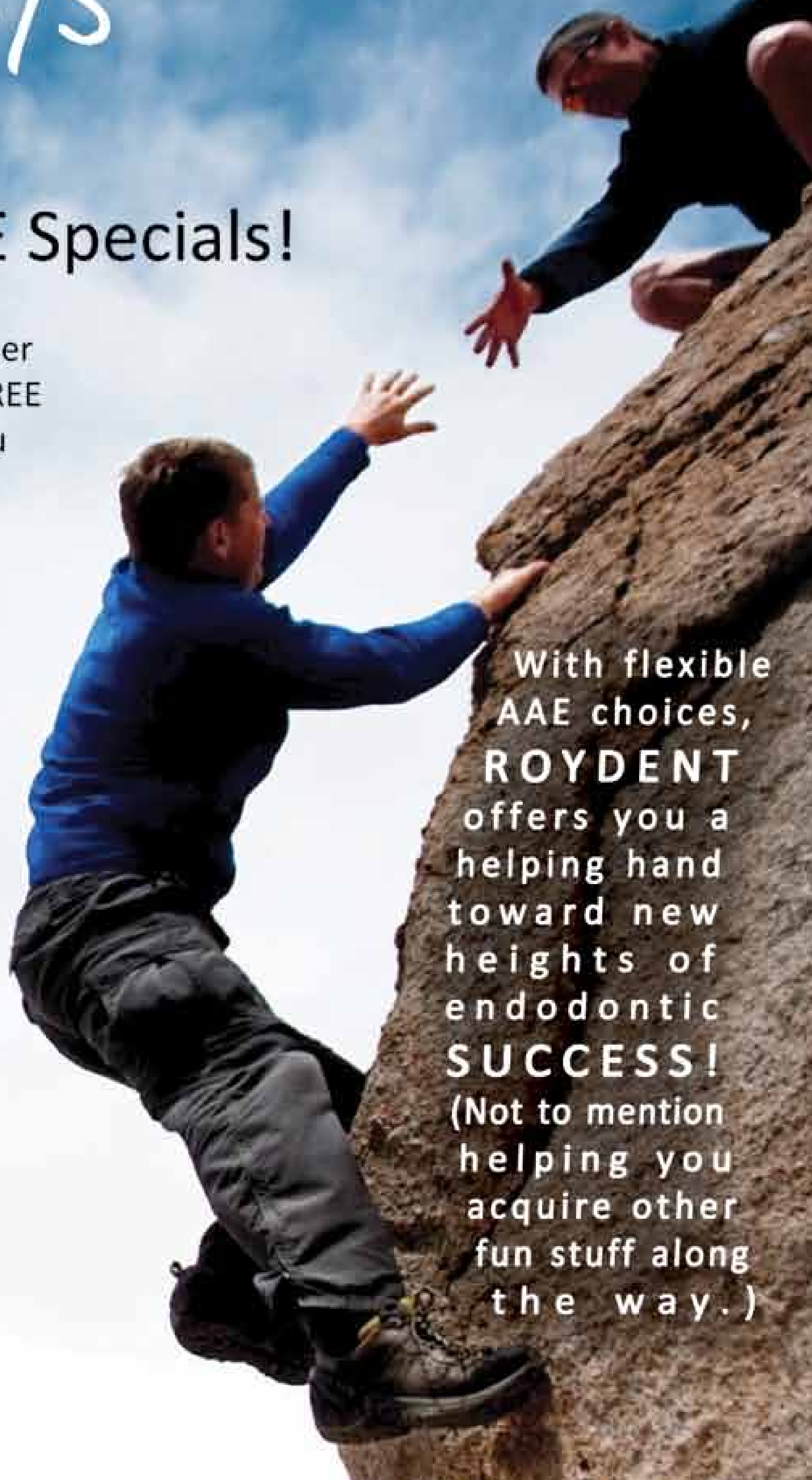

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chemicals and the choice of curing techniques used for bonded restorations.[19]

Studies suggest there are at least two forms of transparent or sclerotic dentin; a form associated with caries and a form associated with age-related changes in the root. The impact upon tooth strength as a function of these altered forms of dentin is not well understood. The long-term predictability of residual coronal tooth structure to function in a manner commensurate with the demands of the orofacial ecosystem, may need to be reassessed in light of observations that sclerotic dentin, unlike normal dentin, exhibits no yielding before failure and that the fatigue lifetime is deleteriously affected at high stress levels.[20] Mechanisms for energy dissipation and crack growth resistance present in young dentin are not present in old dentin. Restorative methods and techniques, particularly as it relates to ferrule creation for endodontically treated teeth, may need to be amplified to address the fact that fatigue crack growth resistance of dentin decreases with age[21] (Fig. 3).

Understanding the mechanical properties of teeth is essential in order to address the most common clinical problem affecting all endodontically treated teeth; fracturing, which in spite of even minimal loss of tooth structure, may be severe enough to necessitate removal.[22-24] The hypothesis that dentin brittleness increases with diminished moisture content has been debunked; conserving bulk dentin is the sine qua non of fracture prevention.

Kuttler et al reported that dentin thickness correlates inversely to post space diameter in the distal roots of mandibular molars.[25] A #4 Gates-Glidden drill caused strip perforations in 7.3 percent of canals studied. The authors recommend Gates-Glidden drills no larger than a size #3 be used. After endodontic treatment, the furcation side dentin thickness was less than 1 mm in 82 percent of the distal roots studied (Fig. 4).

There are primary causes that predispose teeth to fracture and secondary causes that predispose fracture after a period of time (Fig. 5). Endodontics is a component of an interdisciplinary process and a chain is only as strong as its weakest link. Subsequent to any endodontic procedure, intensity of stress concentration and tensile stresses within an endodontically

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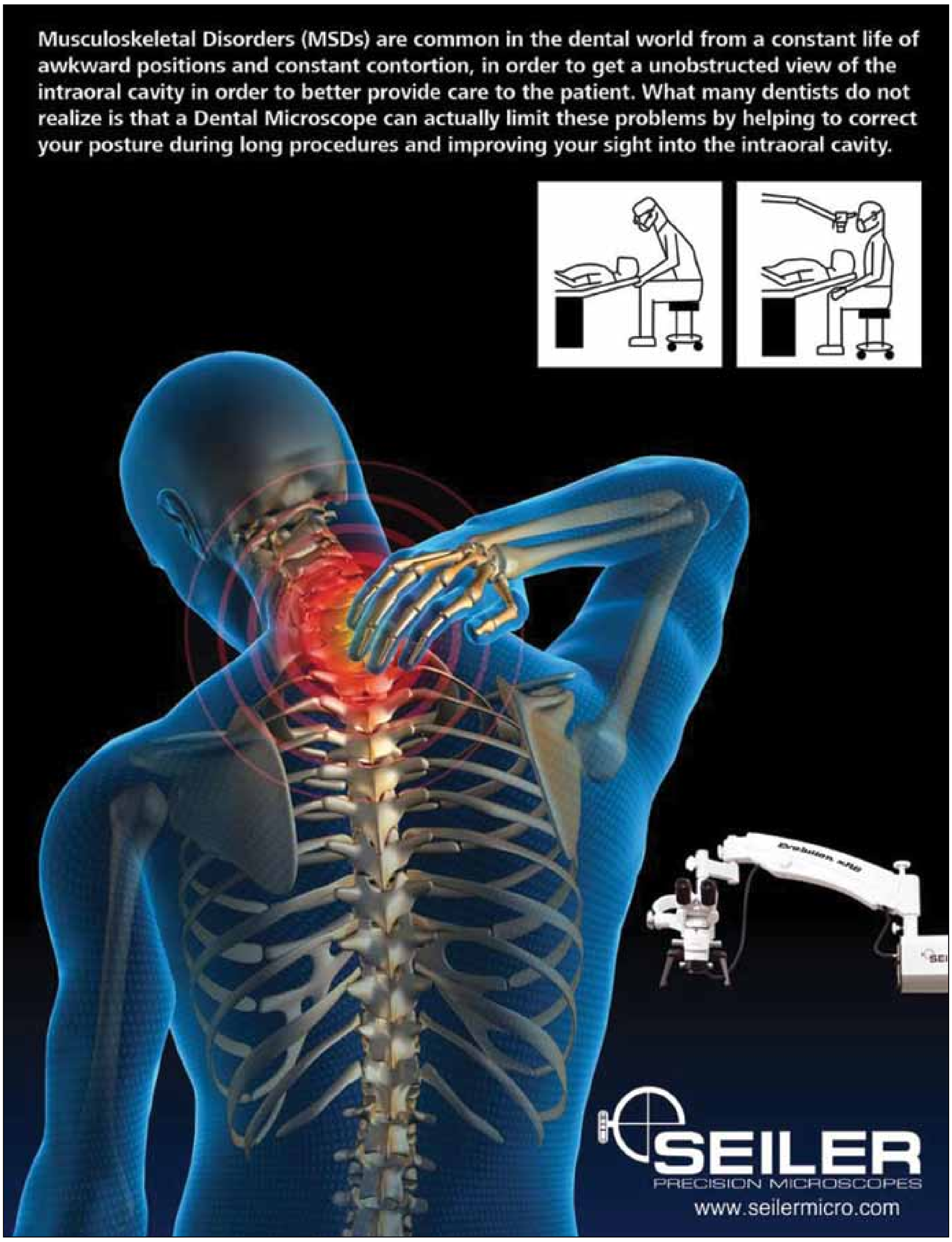

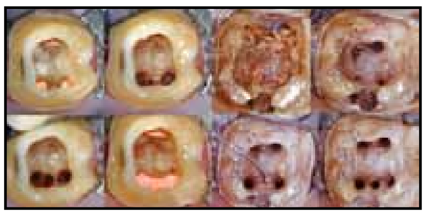

Fig. 3: Two different retreated teeth; two different potential treatment outcomes. The root-canal system of both teeth has been reengineered in its anatomic entirety; however, the treatment outcome after restoration for both is unlikely to be the same. Regenerative technologies incorporating mesenchymal stem cells derived from dental tissues may one day obviate the concern.

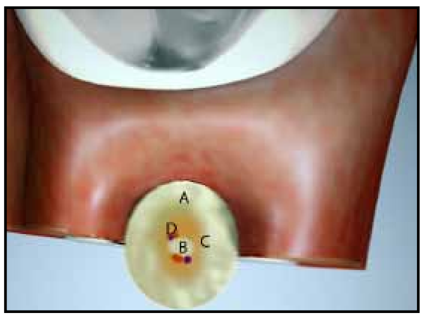

Fig. 4: A) Less porous, less hydrated and highly mineralized outer dentine. B) Pulp canal space. C) More porous, more hydrated and less mineralized inner dentin. D) Water in the dentinal tubules and pulp space is held in a confined environment under hydrostatic pressure.

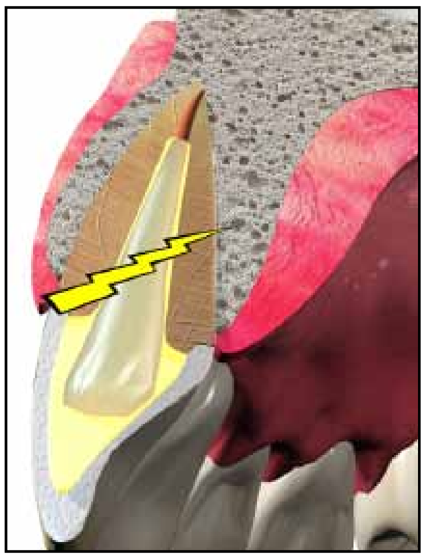

Fig. 5: Primary causes of fracture include excessive structure loss, loss of free unbound water from the root canal lumen and dentinal tubuli, age-induced changes in the dentin and restorations and restorative procedures. Secondary causes of fracture include the effects of endodontic irrigants and medicaments on dentin, the effects of bacterial interaction with dentin substrate and biocorrosion of metallic post-cores.

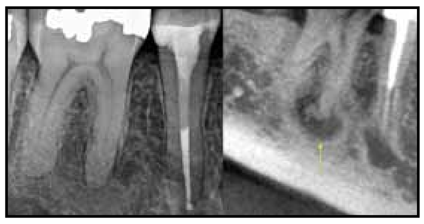

Fig. 6: The image on the left is a flat field periapical radiograph; the one on the right, a small focal field cone beam volumetric tomograph (Kodak 90003D, Kodak Dental Systems, Woodbridge Conn.). The differential in visualization of periapical pathology from a 3-D to a 2-D image is as much as 2:1 (Estrela et al, 2009).

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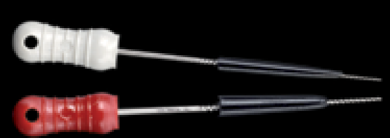

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treated tooth will depend upon 1) the material properties of the crown, post and core material chosen, 2) the shape of the post, 3) the adhesive strength at the crown–tooth, core–tooth and core– post, post–tooth interfaces, 4) the magnitude and direction of occlusal loads, 5) the amount of available tooth structure and 6) the anatomy of the tooth. Any combination of vectored stress concentration and high tensile stresses will predispose these teeth to fracture without an adequately engineered restorative design.

Reengineering

Reengineering negative treatment outcomes is a significant part of the contemporary endodontic oeuvre. The presence of apical periodontitis may or may not affect the outcome of ini-

Fig. 7: The initial endodontic treatment procedure was inadequate and failing. Reengineering (inclusive of interim calcium hydroxide therapy) ensured optimal eradication of microflora from the root canal space, and the obturation produced definitive closure of the apical termini. Surgery was performed to redress persistent symptoms.

tial endodontic treatment[26]; however, there is a general consensus that apical periodontitis is the most important variable influencing a positive outcome with non-surgical and surgical retreatment.[27-29] Positive treatment outcomes may be more likely in certain teeth with a combination of both procedures rather than with one or the other alone (Fig. 6).

The premise that non-surgical retreatment improves the outcome of periapical surgery has been supported by both historical and current studies.[30-32] Apical surgical “correction” of intracanal infections may isolate, but not eliminate, the residual microflora of the root canal space. It should therefore be limited to situations where non-surgical retreatment is judged impractical. With the range of sophisticated equipment and material in the conventional endodontic armamentarium, this is a remote consideration at best. When the etiology is independent of the root-canal system, surgery is the most beneficial treatment.[33] Non-surgical retreatment may still be indicated in these cases, especially when intracanal infection cannot be ruled out. Time constraints or financial pressures should never be a factor in making surgery the first treatment choice (Fig. 7).

The variables associated with non-surgical retreatment are myriad and treatment outcome studies in endodontics have been egregiously abused by those wishing to diminish the value of reengineering natural teeth. Many studies have categorized teeth with caries, fractures, periodontal involvement and poor coronal restorations as negative endodontic outcomes.[34,35]

Prior procedural errors[36], occlusal considerations[37], material choice for the restoration[38] and design of the full coverage component all suggest that success is a function of comprehensive treatment planning as much as technical expertise. Evidence-based or controlled best evidence studies should conclude these are non-endodontic causes of failure and the success of endodontic treatment itself is high and predictable.

Kvist and Reit[39] have shown that while surgical cases may demonstrate higher healing rates than non-surgical retreatment cases initially, four years out there was no difference between the two modalities due to “late” surgical failure. The failure rate for surgical therapy appears to be analogous to the failure rate for retreatment as a function of the size of the lesion treated.[40] Levels of apical resection[41] and the type of root end filling material make a difference in surgical treatment outcome success[42]; however, the dentin bonded composite technique and the use of compomer materials has not been widely reported. As these techniques dome the resected root face, sealing off the cut tubuli, they may prove to be the most effective retrograde surgical protocols of all. In regard to periapical re-surgery, the literature is unclear.

Gagliani et al[43] compared periapical surgery and re-surgery over a five-year follow-up period. Using magnification and microsurgical root-end preparations, the positive outcome for primary surgery was 86 percent and 59 percent for re-surgery. While others have shown positive outcomes for re-surgery, the decision remains highly case specific. In spite of our best efforts, negative endodontic treatment outcomes occur and orthobiologic replacement of teeth and their surrounding anchoring structures is an integral part of contemporary foundational treatment planning.

A recent article by Assuncao et al[44] describes engineering methods used in dentistry to evaluate the biomechanical behaviour of osseo-integrated implants. Photo-elasticity is used for determining stress concentration factors in irregular geometries. The application of strain-gauge methodology on dental implants provides both in vitro and vivo measurement strains under static and dynamic loads. Finite element analysis can simulate stress using a computer-created model to calculate stress, strain and displacement.

An analysis of the impact of

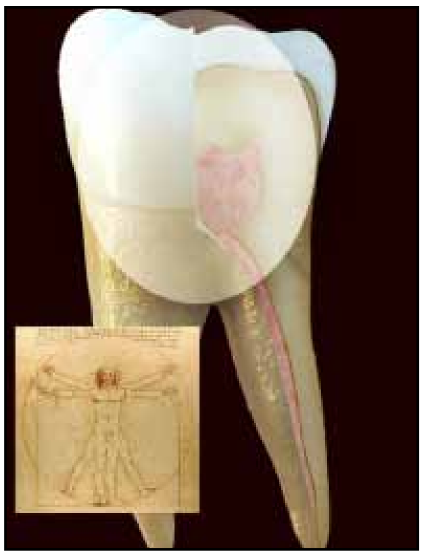

Fig. 8: The strength of the 'egg like' coronal structure of a tooth can support substantial occlusal stress and force; however, disrupting the integrity of the 'dome' or roof of the pulp chamber with an access preparation will invariably lead to a statistically significant degree of fracturing after endodontic therapy.[16]

mechanical/technical risk factors on implant-supported reconstructions is beyond the scope of this publication; however, the replacement of lost teeth by implants should, without exemption, provide a feeling of *restitutio ad integrum.* The means by which the restoration of the original condition at the "crown/root" interface is idealized will be detailed.

"The structure and composition of teeth is perfectly adapted to the functional demands of the mouth, and are superior in comparison to any artificial material. So first of all, do no harm ..."
– Anonymous

Back to the egg

An increased uniform amount of coronal dentin significantly amplifies the fracture resistance of endodontically treated teeth regardless of the post system used or the choice of material for the full coverage restoration.[45] A recent article by Coppede et al demonstrated that friction-locking mechanics and the solid design of internal conical abutments provided greater resistance to deformation and fracture under oblique compressive loading when compared to internal hex abutments.[46] These two "seemingly" disparate observations define the inherent continuum between natural tooth engineering and the principles of engineering necessary to orthobiologically replicate the native state.

The use of a ferrule or collet and a bonded or intimately fit post-core to restore function and form to an endodontically treated tooth is analogous to the use of a long, tapered friction fit interface with a retaining screw (Morse taper) to secure an abutment to a fixture. In both cases, the role of contact pressure between mating surfaces to generate frictional resistance provides a locked connection. This has been shown to affect long-term stability of crestal bone support for the overlying gingival tissues and maintains a healthy protective and esthetic periodontal attachment apparatus[47].

The Roman architect Vitruvius' (Marcus Vitruvius Pollio) description of the perfect human form in geometrical terms was a source of inspiration for Leonardo da Vinci who successfully illustrated the proportions outlined in Vitruvius' work "De Architectura." The result, the Vitruvian man, is one of the most recognized drawings in the world and is accepted as the standard of human physical beauty. Vitruvius theorized that the essential symmetry of the human body with arms and legs extended should fit into the perfect geometric forms; the circle and the square. It took Leonardo Da Vinci to recognize that the circle and the square are only tangent at one place, the base. Observe the insert in Fig 8. The stabilizing platform for the human form outlined begins at that tangent; the intersection is graphically analogous to the structural configuration of platform switching.

The relative simplicity of this construct reinforces the obvious. When we compare design in living things to the artificial designs they inspire, a striking parallel emerges. Almost all the products of man's technology are no more than imitations of those in nature and usually, they fail to match the superior design in living things.

Consider the engineering perfection that is the egg. Its strength lies in its oblate spheroid shape. A blow to the side of an egg from a sharp object puts pressure across the thin shell and breaks it easily. However; if the egg is squeezed directly on its poles, the vectored pressure is compressed along the surface structure, not across the shell; the egg cannot be broken without extraordinary force. However, if a pin hole is created in one of the poles disrupting the integrity of the structure, the pressure will readily break the egg, commensurate with a sharp blow to the side.

In geometry, an oval is a curve resembling an egg or an ellipse. Architects and engineers have used smooth ovate curves to support the weight of structures over an open space literally since the second millennium BC. These arches, vaults and domes can be seen in buildings and bridges all over the world; the most pervasive example being the keystone arches used by the Romans for aqueducts and mills.

An arch directs pressure along its form so that it compresses the building material from which it is constructed. Even a concrete block is readily broken if you hit it on the side with a sledgehammer. But under compression forces from above, the

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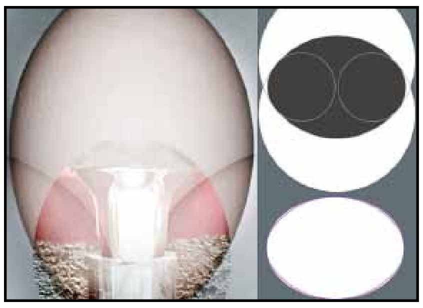

Fig. 9: An arch eliminates tensile stresses in spanning an open space as all forces are resolved into compressive stresses. It requires all of its elements to hold it together, thus making it self-supporting. The incorporation of platform switching into the design of an implant abutment simulates three oblate spheroid shapes; one vertical, two horizontal. The objective is to ensure axially vectored compressive stresses are contained within an idealized shape that is structurally enhanced by the use of a precise friction fit connection.

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block is incredibly strong and unyielding. Many will remember the weight-bearing tripod experiments from grade school where an egg acts as one of three supporting legs of a square section of wood bearing books as the load. The structure could support more than 60 books, almost 20 pounds, before breaking the supporting egg. One need only look at the root trunk and coronal tooth structure of a multi-rooted teeth and it becomes apparent that strength of the tooth form is dependent upon an arch form for its integrity (Figs. 8, 9).

Is it possible for this natural feat of engineering wonder to be biomimetically replicated to the design parameters of osseo-integrated implants? There are a number of paradigms that continue to fuel debate in the dental clinical and scientific communities pertaining to the optimal engineering predicates for implant design. These include smooth vs. rough surfaces, submerged vs. non-submerged installation techniques, mixed tooth-implant vs. solely implant-supported reconstructions, Morse taper abutment fixation vs. a butt-joint interface and titanium abutments vs. esthetic abutments in clinical situations where esthetics is of primary concern.

The cone-screw abutment has been shown to diminish micromovement by reducing the burden of component loosening and fracture. This enables the identification of the effects of the parameters such as friction, geometric properties of the screw, the taper angle and the elastic properties of the materials on the mechanics of the system. In particular, a relation between the tightening torque and the screw pretension is identified. It was shown that the loosening torque is smaller than the tightening torque for typical values of the parameters. Most of the tightening load is carried by the tapered section of the abutment, and in certain combinations of the parameters the pretension in the screw may become zero.

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Biomechanics

"The seed of a tree has the nature of a branch or twig or bud. It is a part of the tree, but if separated and set in the earth to be better nourished, the embryo or young tree contained in it takes root and grows into a new tree."
— Newton

Pressure on the cervical cortical plate, micro-movement of the fixture-abutment interface (FAI) as well as microflora leakage and colonization at and within the FAI are some of the pathologic vectors associated with osseous remodeling, both crestal and peripheral to dental implants.[48] Occlusal considerations engineered into fixture design should enable optimum load distribution for permanent load stability during functional loading, reduce functional stress transfer

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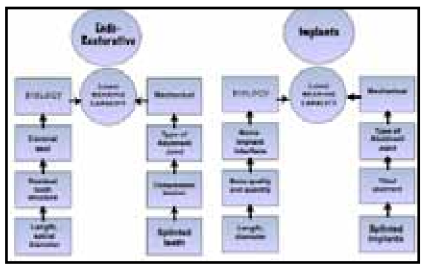

Fig. 10a: Foundational dentistry mandates that the impact of an orthobiologic replacement unit be commensurate with the biologic objectives and functional requirements of the natural tooth.

Fig. 10b: As the number of implant-supported single tooth replacements increases, implant-abutment connection design should ensure that occlusal table replication displays equivalency in both dimension and cuspal inclination with the surrounding natural dentition.

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