# Fibre-Reinforced Composites in Restorative Dentistry

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*Abstract:* **Restorative dentistry is constantly evolving as a result of innovative treatment solutions based on new materials, treatment techniques and technologies, with composite materials being a prime example. The advent of fibre reinforcement has further increased the potential uses of composites within restorative dentistry. This paper discusses fibre types, structure and the physical properties of fibre-reinforced composites, in addition to outlining some of the potential clinical applications of this exciting group of materials, thus updating the reader on the new treatment possibilities offered by these developments.**

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*Clinical Relevance:* **Fibre reinforcement has expanded the clinical applications of resin composite materials.**

Fibre-reinforced composites (FRCs) were first described in the 1960s by Smith[1] when glass fibres were used to reinforce polymethyl methacrylate. In the 1970s, carbon fibres were also used to reinforce acrylic resins[2] and, in the 1980s, similar attempts were repeated.[3,4] In the 1990s, FRCs were used to fabricate fixed prosthodontic restorations.[5] Since then, there has been a steady increase in research into this interesting group of materials. It has been suggested recently that resin-bonded, glass fibre-reinforced fixed partial dentures (FPDs) may be an alternative to resin-bonded FPDs with a cast metal framework.[6] In 1973, a report was published of a one-visit technique to replace the patient's natural avulsed or electively extracted anterior tooth crown using the acid etch technique.[7] In the same year, Rochette published his description of a two-visit technique utilizing a cast gold splint and acid etch retention, which was also suggested as a means of replacing missing anterior teeth.[8] When stock acrylic pontics were used with acid etch composite retention, the weakness of the acrylic/composite bond and of the composite connectors contributed to early failures.[9] Attempts at reinforcing the connectors with stainless steel pins or wire mesh embedded within the composite were only partially successful because of the lack of stable bonding between the metal 'reinforcement' and the composite resin.[10] Metallic inclusions do not adequately increase the fatigue resistance of composite.[11] FRC has excellent fatigue resistance because the embedded fibres are bonded to the polymer matrix and distributed throughout the length of the prosthesis. The fibres allow the stresses to be redistributed effectively throughout the restoration.[12]

Brown[13] discussed the current dental applications of fibre reinforcement, including dental cements and splints, fibres made into structures for use in direct and indirect composites and denture bases. The contemporary use of fibres in fixed partial dentures were reviewed, their role in biomedical implants was surveyed and their future potential was forecast.

Göhring *et al.*[14] concluded that bonded glass fibre-reinforced, inlay-retained FPDs were successful after two years. They concluded that more research was necessary to optimize framework design and its copolymerization to veneering materials.

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## DEFINITION

Fibre-reinforced composite restorations are resin-based restorations containing fibres aimed at enhancing their physical properties.

This group of materials is a very heterogeneous one depending on the nature of the fibre, the geometrical arrangement of the fibres and the overlying resin used. The fibres within the composite matrix are ideally bonded to the resin via an adhesive interface (Figure 1a). The role of the fibres is to increase the structural properties of the

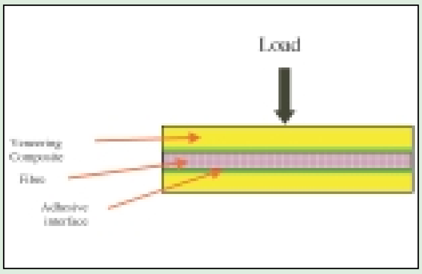


**Figure 1a.** *A diagram demonstrating the structure of a fibre-reinforced composite containing unidirectional fibres.*

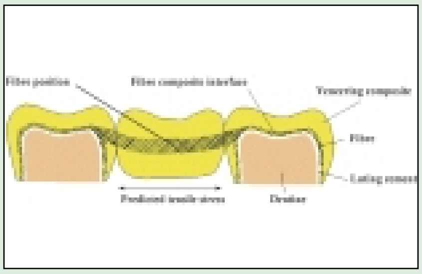

**Figure 1b.** *A schematic diagram illustrating the different parts of fibre-reinforced bridge. For maximum performance the fibre reinforcement should be positioned as close to the tensile side as possible in the pontic region.*

material by acting as crack stoppers.

The resin matrix acts to protect the fibres and fix their geometrical arrangement, holding them at predetermined positions to provide optimal reinforcement. The interface between the two components plays the vital role of allowing loads to be transferred from the composite used to replace missing tooth structure to the fibres (Figure 1b).

## FIBRE CLASSIFICATION

Reinforcing fibres are presented to the dentist in several ways (Figure 2). Table 1 lists products and classifies them according to material composition, fibre architecture within the restoration, surface impregnation status and whether the product is designed for chairside or laboratory use.

The main materials used are glass, ultra-high molecular weight polyethylene and Kevlar fibres. The fibres can be arranged in one direction (unidirectional fibre reinforcement) with the fibres all running from one end of the restoration to the other in a parallel fashion (Figure 3a). Alternatively, the fibres can be arranged in different directions to one another resulting either in weave or mesh-type architectural patterns (Figures 3b and c).

The surfaces of the fibres supplied by the manufacturer are either pre-impregnated with resin and ready to bond to the overlying composite, or require chairside pre-impregnation prior to bonding to the overlying composite.

Dental manufacturers currently supply only standard industrial fibres, however, there is wide variation between products in respect of fibre surface treatments, methods of incorporating the fibres into the polymeric resin, and chairside and laboratory processing methods. In the Vectris system [Ivoclar, Schaan, FL], the glass fibres are pre-impregnated with bisphenol A glycidyl methacrylate (Bis-GMA) which allows cross-linking with the overlying composite structure. However, the glass fibres produced by Stick [Stick Tech Ltd, Turku, Finland) are pre-impregnated with light curing monomers which cross-link during polymerization of the overlying composite, forming a multiphase polymer network. Some of the fibres produced are intended for direct intra-oral use or may be used indirectly, whereas others are designed for laboratory handling only.

The key factors which influence the physical properties of FRC structures are listed as follows:

- Fibre loading (volumetric fraction) within the restoration;
- The efficacy of the bond at the fibre-resin interface;
- Fibre orientation relative to load;
- Fibre position in restoration.

### Fibre Loading (Volumetric Fraction) within the Restoration

Increasing the quantity of the fibres in the polymer matrix enhances the fracture resistance of the restoration.[16] In the clinical situation it is important that a balance is struck between optimizing this factor, whilst allowing enough space for the overlying veneering composite. This is necessary in order to allow appropriate changes of contour and finishing to be undertaken whilst preserving optimal aesthetics. Care is needed during finishing as, if the fibre reinforcement is exposed, degradation of the resin-fibre interface can occur, leading to early failure of the restoration.

### Fibre Matrix Interface

The structure and properties of the fibre-matrix interface (Figures 1a and b) play a major role in the mechanical and physical properties of FRC materials. In particular, the large differences between the elastic properties of the matrix and the fibres have to be communicated through this interface. Thus the wetting of the fibres by resin by either the dentist or dental technician plays an important role in the efficiency of reinforcement.

### Fibre Architectures and Orientations

Unidirectional fibres (Figure 3a) give anisotropic mechanical properties to the composite (i.e. they improve the mechanical properties in a single direction). They are most suitable for applications in which the direction of highest stress is predictable (Figure 1b).

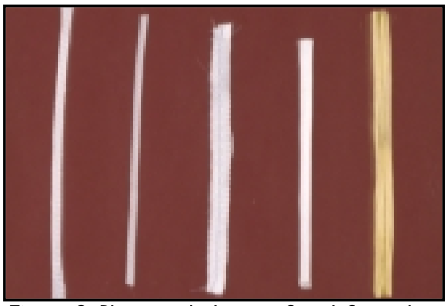

**Figure 2.** *Photograph showing, from left to right, Connect fibres (Kerr, USA), Ribbond fibres (Ribbond, Inc., USA), Fibre-splint (Polydentia, Inc., Switzerland), Stick Tech fibres (Stick Tech Ltd., Finland) and Fibreflex fibres (Biocomp, USA).*

| Product | Company | Fibre type | Fibre architecture |
|---|---|---|---|
| **Pre-impregnated, laboratory products** | | | |
| FibreKor | Jeneric/Pentron | Glass | Unidirectional |
| Vectris pontic | Ivoclar | Glass | Unidirectional |
| Vectris frame and single | Ivoclar | Glass | Mesh |
| everStick net | Stick Tech Ltd | Glass | Mesh |
| **Pre-impregnated, chairside products** | | | |
| Splint-It | Jeneric/Pentron | Glass | Unidirectional |
| Splint-It | Jeneric/Pentron | Glass | Weave |
| Splint-It | Jeneric/Pentron | Polyethylene | Weave |
| everStick | Stick Tech Ltd | Glass | Unidirectional |
| **Impregnation required, chairside products** | | | |
| Connect | Kerr | Polyethylene | Braid |
| DVA Fibres | Dental/Ventures | Polyethylene | Unidirectional |
| Fibre-splint | Polydentia Inc. | Glass | Weave |
| Fibreflex | Biocomp | Kevlar | Unidirectional |
| GlasSpan | GlasSpan | Glass | Braid |
| Ribbond | Ribbond | Polyethylene | Leno Weave |
| **Pre-impregnated prefabricated posts** | | | |
| C-Post | Bisco | Carbon | Unidirectional |
| FibreKor | Jeneric/Pentron | Glass | |

***Table 1.*** *Classification of fibre-reinforced composite and dental products (adapted from Freilich et al.*[15]*).*

Possible uses of this type of material in prostheses would include the pontic regions of FRC-fixed bridges.[17] Fibre weaves in two directions (bi-directional fibres), as depicted in Figure 3c, allow for multi-directional reinforcement of the restoration, and are therefore useful when it is difficult to predict the direction of highest stress in prosthesis, e.g. full crown restoration or denture repairs in Case 2.

## Fibre Position in the Restoration

In a unidirectional fibre composite, in which the fibres are parallel and run in one direction, the physical properties are highest in the direction parallel to the fibres and lowest in the direction perpendicular to the fibres. It is desirable to place the fibres parallel to the highest anticipated stresses in the dental restoration. Finite element studies have revealed that the areas of greatest stresses in a three-unit bridge are generated at the fit or tissue surface of the bridge (where all the stresses will be tensile), between the abutment and the pontic and around the abutment near the edentulous space.[18] Technicians required to fabricate FRC bridgework should be given clear guidance in regard to the optimal design for these restorations and they should be instructed to place the fibre reinforcement as close to the tissue (tensile) side of the restoration as the dictates of aesthetic considerations and the requirements for correct restoration seating allow (Figure 1b).[19]

## VENEERING COMPOSITE OVERLAY

The overlying composite must provide:

- Adequate wear resistance;
- Aesthetic properties;
- Adequate physical properties.

A number of manufacturers now supply specific dental composite materials which they consider suitable for meeting all of the above requirements. Ellakwa *et al.*[20] have shown that the composition of the overlying veneering composite has a significant role in the rigidity of the final restoration, which in some cases may approximate that of the underlying dentine.

## BONDING OF FIBRE-REINFORCED COMPOSITE RESTORATIONS

Indirect FRC restorations should be bonded using resin-based composite luting cements (RBC). Ellakwa *et al.*[21] have shown that grit-blasting and silanization of the fitting surface of

a b c

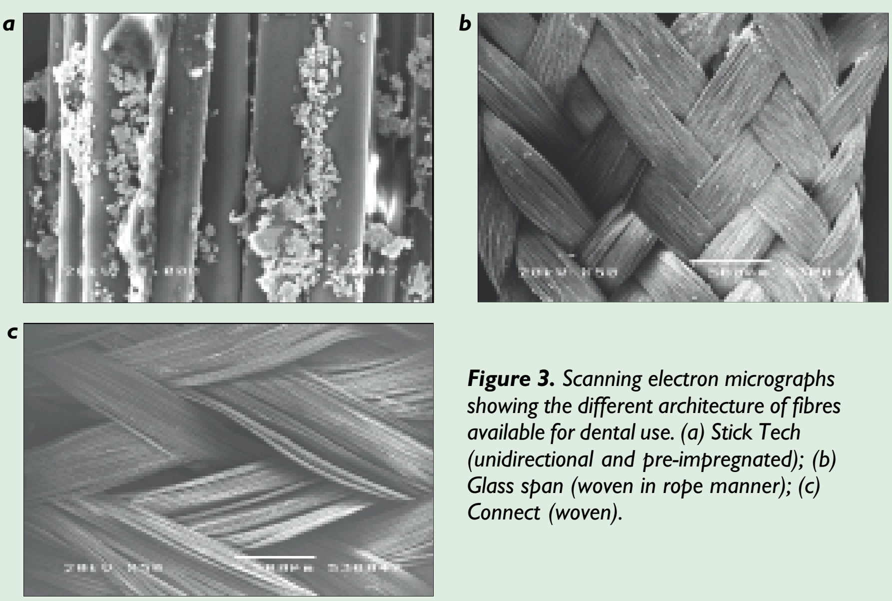

***Figure 3.*** *Scanning electron micrographs showing the different architecture of fibres available for dental use. (a) Stick Tech (unidirectional and pre-impregnated); (b) Glass span (woven in rope manner); (c) Connect (woven).*

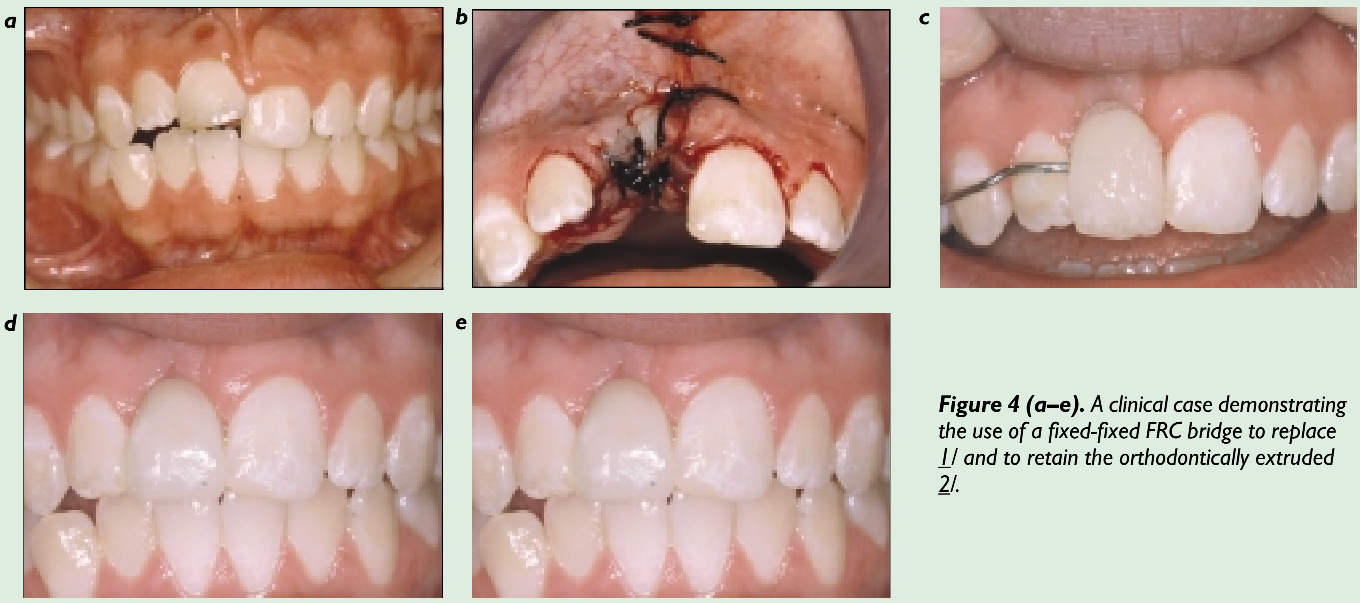

***Figure 4 (a–e).*** *A clinical case demonstrating the use of a fixed-fixed FRC bridge to replace 1/ and to retain the orthodontically extruded 2/.*

indirect dental composite before luting significantly improves the fracture resistance of the adhesive joint and this is to be recommended.

## CLINICAL APPLICATIONS

FRC materials have many applications in dental practice (Table 2), although these materials are not appropriate for all clinical circumstances. It is important when considering the use of a FRC restoration to weigh up the potential disadvantages as well as the advantages of this group of materials (Table 3).

### Case 1

Figure 4a shows the pre-treatment view of an 18-year-old female patient who presented with labially displaced 21/ following trauma. 1/ subsequently suffered extensive root resorption and was extracted. A labial frenectomy and gingivoplasty were performed at the same visit (Figure 4b). 2/ was subsequently realigned with a removable orthodontic appliance which incorporated prosthetic replacement of 1/ (Figure 4c). Finally, a fixed-fixed, indirectly fabricated, FRC bridge was used to restore the 1/ space (Figure 4d). Figure 4e shows the labial view 18 months postoperatively.

### Case 2

Figures 5(a–d) show the use of a fibre mesh (Stick Net) to repair a crack in a maxillary complete denture.

### Case 3

Figures 6a and b show pre- and post-treatment views of the replacement of a failed metal-ceramic bridge with a three unit fixed-fixed FRC bridge restoring the lower right first molar.

### Case 4

Figure 7 demonstrates the use of FRC as a periodontal splint in a patient with an acquired oral defect following ablative surgery.

## DISCUSSION

The cases illustrated demonstrate a few of the potential clinical applications of FRCs in restorative dentistry, although this is an ever increasing area (Table 2). The patient illustrated in Case 1 could have had the 1/ space restored with a conventional metal-ceramic bridge or an adhesive bridge with a cast metal framework. The former option would have involved significant tooth destruction, jeopardizing long-term tooth vitality. Long-term aesthetics could also not be guaranteed with this alternative. A conventional metal framework, resin-bonded bridge would have demanded extensive palatal enamel coverage of 2| and |1 retainers to ensure post-orthodontic stability and to reduce the chances of unilateral debonding. When anterior teeth are thin and/or translucent, incisally metal 'shine through' may destroy aesthetics and opaque luting cements only offer a compromise solution. A two unit cantilever design of prosthesis would not require as extensive palatal abutment coverage to resist bridge debonding as inter-abutment debonding forces cannot

- Reinforced direct composite restoration.
- Single indirect restorations (inlay, onlay, partial/full veneer crowns).
- Periodontal splinting/post trauma splints.
- Immediate replacement transitional and long-term provisional bridges.
- Fixed bridgework – anterior and posterior:
  - *Simple cantilever;*
  - *Fixed-Fixed;*
  - *Implant supported.*
- Reinforcing or repairing dentures.
- Fixed orthodontic retainers.

***Table 2.*** *Clinical application of fibre-reinforced composites in dentistry.*

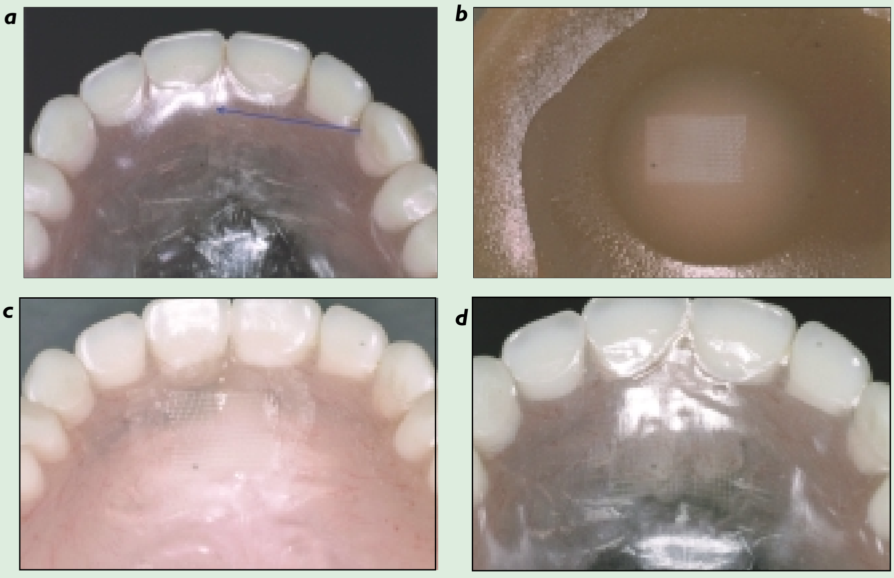

*Figure 5 (a–d). A clinical case demonstrating the use of fibres to repair a crack in a maxillary complete denture.*

be generated, but such a design would not have provided post-orthodontic stabilization for this patient. Whilst clinical studies have demonstrated the superiority of two unit cantilever designs over fixed-fixed designs for cast metal wing-retained, resin-bonded bridges,[22] it is not certain whether such a design is to be generally preferred for FRC bridges. The large elastic modulus mismatch between the composite resin lute and the non-precious alloy retainer wings of a fixed-fixed resin-bonded bridge frequently leads to fatigue stressing overcoming the structural integrity of the resin lute interface.[23] The high fatigue resistance of FRC may result in improved stress distribution and clinical longevity of FRC splints and bridges in situations where functional occlusal surfaces of abutments remain uncovered, but evidence from prospective controlled clinical trials are required to verify this hypothesis.

## SUMMARY

The use of FRC restorations in clinical dentistry is increasing, as their potential for extending the range of possible treatment needs met by resin-based composites is being realized. An appreciation of the critical factors which impact on the properties and clinical service potential of these restorations will assist the practitioner and dental technician in designing and delivering high quality restorations, which will maximize the success rate and longevity of these new materials.

It is likely that research with new materials not yet used in biomedical applications will further extend the potential of these materials. The pace of change in this field is so rapid that the future is very encouraging.

**Advantages**
- Lower treatment costs.
- Single visit immediate tooth replacements.
- Suitable for transitional and long-term provisional restorations.
- Readily repaired.
- Suitable for young patients (developing dentition) and elderly (time saving).
- Metal free restoration.
- Improved aesthetics.
- Can be produced in a simple manner in the laboratory without the need for waxing, investing and casting.
- Can frequently be used with minimal or no tooth preparation.
- Wear to opposing teeth much reduced in comparison to traditional metal-ceramic restorations.

**Disadvantages**
- Potential wear of the overlying veneering composite especially in patients with significant parafunction.
- May lack sufficient rigidity for long span bridges.
- Excellent moisture control required for adhesive technique.
- Space requirements are greater in posterior occlusal situations in comparison to metal occlusal surfaces (to allow sufficient room for fibres and adequate bulk for veneering composite overlay).
- Uncertain longevity in comparison to traditional techniques.

***Table 3.*** *Advantages and disadvantages of FRCs in dentistry.*

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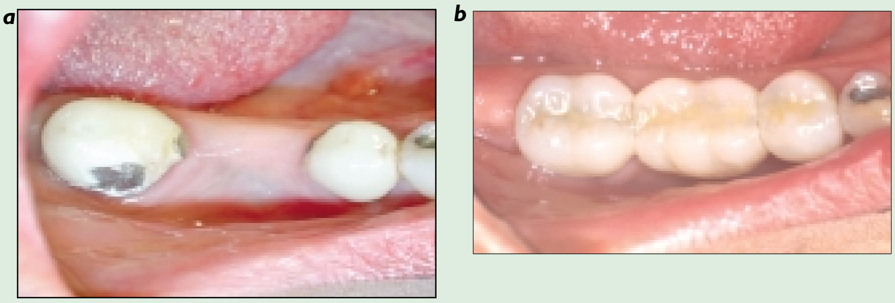

***Figure 6(a, b).*** *Photographs showing pre- and post-treatment views of a three-unit, fibre-reinforced bridge replacing the lower right first molar.*

***Figure 7.*** *A clinical case demonstrating the use of an indirect FRC splint to immobilize maxillary teeth in a patient with a surgically acquired oral defect (courtesy of Dr M.J. Shaw).*


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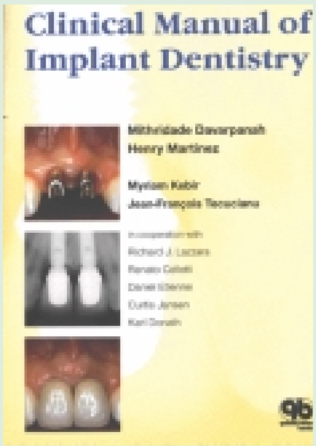
## BOOK REVIEW

**Clinical Manual of Implant Dentistry.** By M. Davarpanah and H. Martinez. Quintessence Publishing Co. Ltd, New Malden, 2003 (220pp., £55). ISBN 1-85097-049-1.




The postcript to this book states that 'the aim is to provide practitioners and students with all the scientific and clinical data necessary to understand implant dentistry'. The result is a very informative reference book that is exceptionally well illustrated and very easy to read.

From the outset, the text is supported by a systematic review of the literature, exploring the range of considerations that need to be accounted for in treatment planning. For reference purposes, both the surgical and prosthodontic success rates from a variety of published studies are nicely presented in a series of tables and pie charts. A chapter is devoted to implant diameters, particularly the indications and limits of narrow and wide platform fixtures. This reinforces the message that planning and attention to detail are prerequisites for implant success and patient satisfaction.

Before dealing with the prosthodontic aspects of treatment, basic surgical techniques, including the all important patient preparation, is dealt with in a concise and informative manner. From a prosthodontist's viewpoint, it was refreshing to see a sympathetic approach to soft tissue management with the description of surgical and prosthetic techniques to promote peri- implant aesthetics.

Almost one third of the book is devoted to the principles of implant-supported prostheses, including abutment selection, treatment concepts and the rationale behind using screw-retained and cement-retained bridges. Treatment considerations for edentulous, partially dentate and single unit cases are covered, again in a methodical, evidence-based manner, backed up with clinical photographs and schematic illustrations. The problems associated with reduced bone volume and space are addressed.

Davarpanah goes on to describe specific surgical techniques to extend implant options. These include procedures such as immediate implant placement, sinus grafting and onlay grafting, guided bone regeneration and osteotomies. The book concludes with some shorter chapters on non-submerged implant techniques and literature review chapters on surface properties and loading concepts.

At just over 200 pages, this was an extremely enjoyable book to read. It is well illustrated and relies on supporting evidence from a good reference base. The basic principles are well covered and I would recommend this book not only to surgeons and dentists practicing in this field, but also to students and practitioners who want to gain an insight into implant dentistry.

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