The Treatment Dilemma of the Furcated Molar: Root Resection Versus Single-Tooth Implant Restoration. A Literature Review

Richard P. Kinsel, DDS*/Robert E. Lamb, DDS, MSD**/David Ho, DDS***

Successful treatment of furcated molar teeth presents the periodontist and prosthodontist with a challenging dilemma. Accepted treatment modalities include chemotherapeutic maintenance, root planing, open flap debridement, modified Widman flap, bone grafting with and without guided tissue regeneration, and osseous resection with and without root removal. Determining the appropriate treatment for an individual patient that is both cost-effective and offers the greatest long-term prognosis can be a daunting task. The literature is replete with studies of different therapeutic alternatives for furcated molar teeth. A relatively new treatment option is complete removal of the tooth combined with ultimate placement of an endosseous implant and restoration with a single crown. A review of the relevant literature with special emphasis on root resection therapy and single molar implant placement is presented. The relative merits of each treatment modality and guidelines for their use are discussed.

(Int J Oral Maxillofac Implants 1998;13:322–332)

Key words: review literature, risk factors, root furcations, root resection, single-tooth implants, survival rate

There is general consensus in the dental literature that as a population ages, molar teeth have a propensity for adverse periodontal involvement, leading to their premature loss. An early study by Marshall-Day and Skourie[1] on radiographic examinations of 568 subjects in India, ages 9 to 60 years old, concluded that the mandibular incisors and molars appeared to be most susceptible to osseous loss. Marshall-Day et al[2] also reported a rise in tooth mortality after age 40, and the maxillary and mandibular molars were the earliest teeth lost. These findings were affirmed by Ramfjord,[3] who reported on a group of boys 11 to 17 years of age residing in Bombay, India. He found that mandibular incisors and maxillary molars had the highest incidence of gingival inflammation and periodontal pockets.

In a later study, Becker[4] reviewed 30 patients ranging in age from 25 to 71 years (mean 44.6 years) who had refused periodontal treatment. The time between initial examination and follow-up was 18 to 115 months (mean 3.72 years). Approximately 10% of the teeth at risk were lost between examinations, and the mandibular first and second molars had the highest incidence, followed by the maxillary molars. Additionally, molar teeth had the highest mean annual pocket depth increase.

Two longitudinal radiographic studies followed the progression of bone loss within the furcated molar. An interesting photodensitometric analysis by Payot et al[5] demonstrated that in an untreated population, the bone inside the furcation of mandibular molar teeth showed a loss of average density during the 2-year observation period. Björn and Hjort[6] assessed the status of the interradicular bone septa from orthopantomographs and bite-wing radiographs of 221 persons during an observation period from 1965

*Assistant Clinical Professor, Department of Restorative Dentistry, Director, Implant Dentistry Program, Buchanan Dental Center, University of California, San Francisco, San Francisco, California.
**Assistant Professor, Department of Periodontology, University of the Pacific, San Francisco, California; Saul Schluger Visiting Professor, University of Washington, Seattle, Washington.
***Former Resident, Buchanan Dental Center, University of California, San Francisco, San Francisco, California.

Reprint requests: Dr Richard Kinsel, 1291 East Hillside Boulevard, Foster City, California 94404.

to 1978. The number of subjects initially determined to have visible interradicular bone destruction was 18% of the population. This percentage increased to 32.3% over the next 13 years. The severity of interradicular loss also increased during the observation period, and a total of 9.5% of the furcated molars were eventually extracted.

The reasons for continued interradicular bone loss in multirooted teeth are well known. Basaraba[7] listed the possible responses by the tooth once the periodontal lesion had invaded the furca zone of a multirooted tooth. These include an increased likelihood for periodontal abscesses, furcal lesions that offer a nidus for pocket formation enveloping adjacent roots, pulpal exposure with pain (confusing the inexperienced therapist), and a predisposition to root caries.

The classification of furcation involvement is based on the extent of periodontal destruction in a horizontal direction within the furcation. Class I connotes incipient bone resorption over the fluting of the root trunk, with slight horizontal destruction of the attachment apparatus, allowing minimal entry into the furcation with a probe of approximately 1 to 2 mm. The class II defect displays partial horizontal destruction of bone within the furcation, allowing entry into the interradicular region with a probe, although full penetration is not possible. The class III lesion occurs when there has been complete destruction of the bone within the furcation, allowing complete passage of the probe.

Interradicular Anatomy

A major complication for the successful management of furcated molars by either the periodontist or the patient is the complex anatomy of the interradicular aspect of the roots. Bower[8] microscopically examined the furcations of extracted maxillary and mandibular molars. A random sample of first permanent molar teeth (114 maxillary and 103 mandibular teeth) were sectioned at right angles to the long axis at a level 2 mm apical to the most apical root division, and then examined using a dissection microscope. Maxillary first molars were concave in 94% of mesiobuccal roots, 31% of distobuccal roots, and 17% of palatal roots, and the deepest concavity was on the interradicular aspect of the mesiobuccal root; mandibular first molars were concave in 100% of mesial roots and 99% of distal roots, and the deeper concavity was found in the mesial root rather than the distal root.

Everett[9] described another anatomic feature of molar teeth that complicates optimal plaque removal—the bifurcational ridge. This structure is located at the junction between the fluting on the radicular and apical surfaces of the root trunk.

In 1964, Masters[10] observed that many multirooted teeth have a slender enamel projection extending from the enamel of the crown into the furcation. No fiber attachment is possible into an enamel surface of these projections; therefore, this aberration may be a predisposing factor in the initial furcal invasion.

As succinctly expressed by Rosenberg,[11p247] "furcation involvement is the bane of every periodontist because it generally is not amenable to definitive management with conventional periodontal procedures. . . . The accumulation of plaque and calculus in the furcation poses an insurmountable challenge even to the most dedicated patient attempting to maintain the interradicular surfaces free of plaque."

In addition to the chronic inflammatory changes associated with plaque retention, the furcation is also predisposed to caries. The removal and restoration of the carious defect is difficult because of poor access, and may lead to pulpal exposure and pathosis. Successful plaque removal may be hindered in the presence of the restoration.

Treatment of the Furcated Molar

Treatment for patients with furcal involvements can be categorized as either nonsurgical or surgical. Although proper diagnosis, patient selection, and accurate prognosis would greatly aid the clinician's decision, the literature is equivocal regarding the results of various therapeutic modalities.

Many researchers have affirmed the inherent difficulty in successful maintenance. Ramfjord et al[12] observed that tooth types affect the response to different treatments. Maxillary molars showed less short-term reduction in pocket depth and more long-term increase in pocket depth than did the other tooth types. Nordland et al[13] acknowledges that the anatomic configuration and reduced accessibility of molar furcations may limit the efficacy of nonsurgical therapy in these sites. The effects of plaque control and root debridement were compared in nonmolar sites, molar flat surface sites, and molar furcation sites. The 19 patients followed, who had no periodontal treatment within the previous 5 years, exhibited generalized periodontitis with clinically detectable furcation involvement in at least two molars. After plaque control and root debridement, a total of 2,472 sites were monitored by recordings of dental plaque, bleeding on probing, probing depth, and probing attachment levels every third month for 2 years. Their results indicated that molar furcated sites with an initial probing depth of 4.0 mm or greater showed a less favorable response to the periodontal therapy than molar flat surfaces or nonmolar sites.

Hirschfeld and Wasserman[14] reexamined 600 patients who had been treated at least 15 years previously. All patients had been under periodic maintenance at 4- to 6-month intervals. They defined the severity of periodontal disease as early (pockets of 4 mm or less, generally combined with gingival inflammation and subgingival calculus deposits), intermediate (pockets of 4 to 7 mm), and advanced (pockets deeper than 7 mm combined with furcation involvement of at least one tooth). Based on these categories, 76.5% were initially classified as advanced, 16.5% as intermediate, and 7.0% as early disease. Periodontal treatment primarily consisted of subgingival scaling and root planing, gingivectomy, and osteoplasty. Furcations were treated with the expectation of reducing pocket depth rather than of eliminating pockets. The pattern of tooth loss was significantly weighted toward maxillary molars, followed closely by mandibular molars; 31.4% of those teeth originally diagnosed as having furcation invasion were ultimately lost.

A companion study by McFall[15] that followed the format of Hirschfeld and Wasserman evaluated tooth loss in 100 surgically and nonsurgically treated and maintained patients. Maintenance ranged from 15 to 29 years, with a median of 19 years. Ninety-five maxillary and 60 mandibular molars were initially diagnosed as having furcation invasion. A total of 98 of these molar teeth were ultimately lost. The author attributed the high loss rate to the difficulty of plaque removal, anatomy of the roots, occlusal stresses, lack of distal bone support, root proximity, and iatrogenic problems.

Pihlstrom et al[16] investigated the results of two periodontal treatment modalities on both nonmolar and molar teeth over a 6.5-year period. Seventeen adult patients received full-mouth root planing. Upon completion of this phase, one half of each patient's mouth was randomly selected to receive a modified Widman flap. Over the examination period, molar teeth exhibited greater pocket depth increases, regardless of the original pocket depths or therapeutic procedure performed. Additionally, 11 of the 453 teeth included at the outset of the study were extracted over the evaluation period. Nine of these extracted teeth were molars.

Wang et al[17] studied the influence of molar furcation involvement and mobility on periodontal attachment level. Twenty-four patients were treated by one of three possible periodontal surgical procedures: pocket elimination surgery, modified Widman flap surgery, or gingival curettage. Once treated, these patients were placed on a 3-month recall interval for maintenance prophylaxis and received yearly examinations for a period of 8 years. Periodontal indices were recorded at entry, at 1 year after treatment, and at the conclusion of the study. Approximately one half of the 165 molar teeth present at baseline showed furcation involvement. Between baseline and the end of the maintenance period, molars with furcation involvement were twice as likely to be lost than molars without furcations. Those teeth with furcations had significantly more mean attachment loss than the teeth without furcations during the maintenance period. When the therapy effects were considered, no statistical differences were found among the teeth treated by pocket elimination surgery, gingival curettage, or modified Widman flap surgery during any of the time periods regardless of the furcation status.

The fact that the progression of periodontitis in the furcation was different than on other tooth surfaces was also confirmed by Kalkwarf et al.[18] They demonstrated that furcation sites tended to lose probing attachment levels regardless of the type of therapy provided.

Grbic and Lamster[19] examined tooth sites associated with clinical attachment loss in chronic adult periodontitis. A total of 75 patients with chronic adult periodontitis were followed longitudinally for 6 months. Mandibular and maxillary molars and maxillary premolars were the teeth that displayed the highest incidence of attachment loss.

Contrary to the generally negative reports regarding long-term maintenance of furcated molar teeth, Ross and Thompson[20] concluded that many maxillary molars with furcation involvement can be managed successfully. One hundred randomly selected patients had 387 maxillary molars with periodontal disease involving their furcations. No osseous surgery was performed, and treatment was limited to scaling, curettage, comprehensive occlusal adjustment, soft tissue surgery, and oral hygiene instruction. The evaluation period varied from 5 to 24 years. Of the 387 teeth studied, 341 (88%) were functioning comfortably at the end of the survey. However, a major limitation of this study was that the diagnosis of all furcations was made solely by radiographs, and periodontal probing depths were not evaluated.

Root Resection Therapy

One of the accepted surgical treatments for selected furcated molar teeth is root resection. The first references to this procedure were in 1884 by Farrar.[21] The technique was refined, and specific indications and contraindications were offered in many subsequent articles.[22–37] The generally accepted indications include:

1. Severe vertical bone loss involving only one root of a mandibular molar.

2. Bone loss involving one or two buccal roots, or a palatal root of a maxillary molar, resulting in furcal invasion that is inaccessible for plaque removal procedures.
3. Exposed roots that are too close together as a result of interproximal bone resorption, to the extent that maintenance of class I or II interproximal invasion is impossible.
4. Furcae exposed through caries or bone loss that cannot be properly restored and would preclude adequate maintenance.
5. Abutments or piers within a fixed partial denture combined with a negative prognosis because of periodontal disease.
6. Multirooted teeth combined with an individual root fracture.
7. Roots of nonvital teeth that cannot be treated by conventional root canal therapy or retrograde techniques because of the presence of lateral canals, partial calcification, dilaceration, pulp stones, perforations, or broken instruments.

Unfortunately, the literature reveals a significant disparity in the long-term prognosis of root resection therapy as reported by different clinicians. Langer et al[38] undertook a study to evaluate the results of root resections performed to eliminate periodontal pockets around teeth with furcation involvement. They reviewed the records of 100 patients who had undergone root resections at least 10 years prior to the study. A randomized, equal number of maxillary and mandibular molars were selected. Failure was defined as loss of more than 50% of the remaining alveolar bone postoperatively, development of unresolved root fractures, untreatable periapical areas, or the presence of unrestorable caries. A significant finding was that 38% of these teeth failed during the 10-year observation period—the majority occurring between the fifth and seventh year, including a predilection for mandibular molars at a 2 to 1 ratio. Langer et al concluded that the initial outcome is favorable but not lasting, and that most instances of breakdown occur between 5 and 10 years. Therefore, they recommended that any study of root resection therapy should be evaluated over a period of at least 10 years, if the results are to be meaningful. Another interesting observation was that maxillary molars failed primarily because of progressive periodontal disease, while mandibular molars succumbed most frequently to root fractures. The authors hypothesized that the maxillary molar periodontal failure appeared to occur in tooth areas that were inaccessible to routine methods of plaque control and maintenance, while mandibular molars frequently served as an isolated abutment for a fixed partial denture replacing at least one tooth and were at greater risk within longer span restorations.

Bühler[39] also presented a 10-year study of 28 root-resected teeth. Failures were grouped into periodontal (loss of alveolar bone height exceeded 50% either at the mesial or distal aspect), technical damage (root fractures, loss of retention of crowns or fixed partial prostheses, caries), and untreatable periapical problems. No failures were observed within the first 4 years after surgery. Three failures (10.7%) occurred during the 5- to 7-year period. Eight to 10 years after initial treatment, a total failure rate of 32.1% was recorded. Endodontic problems were the major contributing factor. The author agreed with the conclusion of Langer et al that long-term maintenance of resected molar teeth is problematic.

Erpenstein[40] reported similar unfavorable results of hemisected molars in patients with an average follow-up period of only 3 years. Thirty-four molars in 28 patients were hemisectioned as indicated by periodontal problems (26.5%), endodontic problems (58.8%), and advanced carious lesions (11.8%). A significant majority were mandibular molars as opposed to maxillary molars. The overall failure rate was 20.6%, and pathologic apical factors were the overwhelming cause.

A recent 10-year retrospective study of 146 root-resected molars reported additional interesting findings. Blomlöf et al[41] reviewed the relative survival rates of resected molar and single-rooted root-filled teeth in 80 patients. Evaluation parameters included conventional periodontal indices, radiographic examination, personal habits, and the design of restorations. Seventy-five percent of the resected teeth were maxillary molars, most with the palatal root retained. The survival rates of the resected molars were 83% at 5 years and 68% at 10 years. Smokers demonstrated a significantly greater failure rate than nonsmokers. Deeper periodontal pockets were found for resected molar teeth with crown restorations that lacked hygienic design, defined as having a gingival margin with an overhang or one that terminates subgingivally. A particularly perceptive conclusion was that "the clinician must remember that by eliminating the furcation, itself an aggravating factor, the therapy may create new potentially aggravating factors such as endodontic insufficiencies and dental restorations with overhangs.[41p201]

However, some authors have reported greater success. Hamp et al[42] described a 5-year follow-up of periodontal treatment of multirooted teeth. One hundred randomly selected patients with 310 multirooted teeth exhibiting various degrees of furcation involvement underwent complete periodontal therapy. Forty-four percent of the original multirooted teeth with furcation involvement were extracted during presurgical treatment or during surgery. Approximately one half of the remaining 175 teeth were root resected. Of these teeth, 10.3% had pocket depths greater than 3.0 mm at 5 years, and an additional 5.8% had carious lesions. Although the results are described by the authors as generally favorable, complications were found in 16.0% of the resected molar teeth at 5 years. Also, the extraction of several of the furcation-affected molar teeth prior to the study's evaluation period would have elevated the overall success.

Klavan[43] evaluated single root amputation of maxillary molars. A total of 34 maxillary molar teeth were studied in 29 patients. The distobuccal root was removed in 30 teeth, the mesiobuccal root in 2 teeth, and the palatal root in 1 tooth. The observation period ranged from 11 to 84 months, with a mean of just over 3 years postoperatively. All of the teeth were in function, and 24 were nonsplinted individual units. Over the study period, only 1 tooth was extracted, none increased in periodontal pocket depth, and 3 showed increased mobility.

Although the evaluation time for both the Hamp et al and Klavan studies fell short of 10 years, the period advocated by Langer et al, other authors have reported long-term root resection results that appear far more favorable. Carnevale et al[44] presented a retrospective analysis of the management of furcated molar teeth. They reviewed a population of 194 randomly selected patients who had received hemisection or root amputation. The sample consisted of 500 sectioned teeth—174 maxillary first molars, 140 mandibular first molars, 101 maxillary second molars, 72 mandibular second molars, 4 maxillary third molars, 6 mandibular third molars, and 3 maxillary first premolars. The majority of the teeth were sectioned as a result of class II or III furcation involvement. A total of 488 teeth were evaluated; 303 teeth were followed for a period of 3 to 6 years, and 185 teeth for a period of 7 to 11 years. The failure rate was 11.8% for the 3- to 6-year group, and 5.4% for the 7- to 11-year group, for a total of 17.2%. Carnevale et al recognized that their reported success conflicted with other studies. An important conclusion was that resection therapy is very technique-sensitive, and that, without proper indications, competent oral hygiene by the patient, and correct restorative expertise, its indiscriminate use should be avoided.

In another, more recent retrospective study by Basten et al,[45] 32 patients with a total of 49 root resections of molars were treated between 1972 and 1993. Eight percent of the molar teeth were extracted during the observation period of 2 to 23 years, with a mean of 11.5 years. However, this study is difficult to compare with others. First, a molar was determined to be a failure only if it was extracted, regardless of periodontal status; therefore, continuing attachment loss over the observation period would not be counted as a failure. Second, no other clinical periodontal parameters that may be of prognostic value were listed. Finally, most patients were treated with complete-mouth reconstruction and incorporation of the resected molars into a cross arch, fixed prosthesis, negating the significant occlusal forces that may adversely affect independent molar restorations or short-span fixed partial dentures.

Single Molar Tooth Osseointegrated Implants

There is no question that the acceptance of osseointegrated dental implants has altered periodontal and prosthodontic treatment options. The literature[46–48] is unequivocal regarding the successful, long-term prognosis of multiple implants placed into the mandibular symphysis and ultimately supporting fixed partial prostheses. However, there are limited retrospective studies of single implants placed and functioning as independent restorations. Obviously, a clinician's decision to place endosseous implants following the extraction of furcated molar teeth, as an option to retention with root resection, should be based on data that specifically address freestanding molar implants.

One of the first retrospective studies was by Engquist et al,[49] evaluating the outcome of 82 single-tooth restorations on Brånemark implants placed from 1984 to 1989. Only one of these implants supported a first molar crown. Marginal bone changes were followed from 1 to 5 years. Two implants were lost (not the first molar) for a cumulative survival rate of 97.6%.

Schmitt and Zarb[50] began a prospective study to evaluate the efficacy of single-implant support for crowns to replace missing teeth. Forty implants were placed between 1985 and 1990, five into the first mandibular molar region. Conventional Brånemark implants were used. All implants remained in function and were successful after being loaded 1.4 to 6.6 years.

A multicenter review headed by Laney[51] again addressed single missing teeth replaced by implants. Ninety-five implants, five of which were placed into the first molar region, were followed for 3 years. The reported cumulative success rate was 97.2%, and none of the molar implants was lost.

Another study by Cordioli et al[52] followed the progress of 61 screw-type implants placed in 43 patients to restore missing single teeth. In 10 patients, two implants were used to replace maxillary or mandibular molars. The implants had a mean loading period of 26 months, ranging from 6 months to 5 years. Periodontal indices, radiographic observation, and Periotest values were recorded. Two of the molar implants failed, both placed in the same patient, and were removed at second-stage surgery. Therefore, the overall success of the molar subgroup of implants had a cumulative rate of 90%.

Haas et al[53] followed 76 Brånemark implants supporting single porcelain crowns over a 1- to 3-year period. Ten of these implants were placed in the mandibular molar regions. None of the molar implants was lost, nor did any demonstrate signs of potential failure.

Avivi-Arber and Zarb[54] reported on 41 patients who had 49 single implants restored with freestanding crowns. Six of those implants were placed into the mandibular first molar regions. Conventional Brånemark implants were used. The observation period ranged from 1 to 8 years after implant loading, with a mean of 4 years. All of the 42 monitored implants were clinically asymptomatic and immobile. No inflammation was observed at adjacent natural teeth. Soft tissue conditions around the single implant-supported restorations were observed to be healthy and paralleled those of the existing natural dentition. Radiographically, each implant was free of signs of interstitial radiolucencies.

Balshi et al[55] treated 47 patients for the replacement of a lost molar with freestanding osseointegrated implants. Twenty-two patients were treated with one implant and 25 with two implants. The implants used the Brånemark protocol; 66 (92%) were placed in the mandible, and 6 (8%) in the maxilla, for a total of 72 implants. The choice between one or two implants was based on the size of the interdental space; a space of 12 mm or greater received two implants. At the 1- and 3-year clinical examinations, a single implant was lost during the healing phase, while all the remaining loaded implants continued to be stable and functioning, for a success rate of 98.6%. The marginal bone loss after 3 years of function was low—0.10 mm for the group with one implant, and 0.24 mm for the group with two implants.

In the same journal, Bahat and Handelsman[56] reported on the use of wide and double implants in the posterior jaw. Fifty-nine freestanding, 5-mm diameter Brånemark implants were placed in the posterior jaws of 45 patients. With the exception of five mandibular premolar sites, all were in the molar regions. The mean loading period was 16 months over a range of 3 to 26 months. Two of the molar implants failed, yielding a success rate of 96.3% over the study period.

Becker and Becker[57] published a retrospective study of single-molar implant-supported crowns over an average of 2 years. Brånemark implants (conventional and wide diameters) were used, 6 placed in the maxilla and 18 in the mandible, for a total of 24 implants in 22 patients. Thirteen implants were immediately placed following molar extraction. Over the 2-year observation period, one implant failed for a cumulative success rate of 95.7%.

A common complication of single-molar restorations supported by external hexagonal implants is abutment screw loosening. The stability of the abutment is highly dependent on the preload torque of the securing screw. Binon[58] has shown that if the preload force is exceeded by the occlusal force during functional loading, micromovement can occur, leading to loss of screw joint integrity.

A recent prospective study[59] of two single-tooth implants (ITI and Astra) reported on preliminary results after 1 year. A total of 102 single-tooth implants were placed in 82 patients at the Finnish Student Health Service Foundation. Eleven of these implants, 4 Astra and 7 ITI implants, were placed into the mandibular molar regions. At the 1-year patient recall, periodontal parameters (degree of plaque formation, Gingival Index, probing depths) and standardized radiographic examinations were assessed. Overall, the marginal bone and peri-implant tissue responses were favorable for both implant systems. Only one of the Astra implants, not a molar implant, was lost prior to loading.

Levine et al[60] reviewed 174 ITI single implants placed in 129 patients by 12 clinicians located throughout the United States. All of the single-tooth implants were loaded at least 6 months and for a median of 12 months. Ninety-four of these implants were placed into the molar regions (19 in the maxilla, 75 in the mandible). Although none of the implants was lost, 3 of the molar implants demonstrated significant bone loss radiographically. Therefore, if these 3 implants are counted as potential failures, the overall success rate of the loaded molar implants was 96.8%. Other complications included loosening of either the seating screw or solid abutment in 8.5% of the molar implant crowns without recurrence after tightening.

Discussion

For a variety of reasons, maxillary and mandibular molars are shown to be more susceptible to periodontal disease. Proper maintenance of molar teeth becomes problematic as apical migration of osseous supporting structures allows bacterial invasion of the fruition. Undeniably, untreated furcated molars will lead predictably to more bone loss.[1–6]

Treatment of furcated molar teeth can be grouped into surgical (with and without root resection) and nonsurgical therapy. Several articles have given results of closed flap maintenance, Widman flap technique, and osseous surgery without root resection.[12–20] With the exception of the Ross and Thompson study,[20] all others describe continuing periodontal attachment and osseous loss with time, regardless of the specific therapy instituted. As mentioned previously, the Ross and Thompson retrospective report relied on radiographs for diagnosis without evaluating pocket depths.

The technique of molar root resection has been recommended for periodontal, endodontic, carious, and iatrogenic problems. The results of the applicable studies[38–45] are equivocal regarding prognosis and, therefore, deserve further discussion.

Recently, Langer[61] has amplified on his original manuscript. He emphasized that the 100 randomly chosen root resections in his study were completed prior to an established protocol for success. Also, the quality of the endodontic treatment, functional loading, and restoration of the molar teeth was not critiqued and, therefore, may not have been optimal. Furthermore, he cautioned against dogmatically choosing one treatment choice for furcated molar teeth over another, concluding that, "There are too many variables in diagnosis, treatment options, and other considerations to predetermine the 'only' treatment for a furcated molar."[61p201]

Of the root resection studies that reported favorable results, Hamp et al[42] and Klavan[43] did not have an observation period of at least 10 years, as recommended by Langer. Therefore, the argument may be made that their initial successes would have ultimately led to failure, if the studies had approached 10 years. Two other reports, those of Carnevale et al[44] and Basten et al[45] describe patients who have been followed after surgery for a period recommended by Langer and, therefore, cannot be easily dismissed. In their conclusion, Carnevale et al did recognize and state that their results conflicted with other studies, concluding that the technique of root resection is dependent on a high level of expertise in all applicable disciplines—periodontal, endodontic, and restorative—as well as on competent oral hygiene by the patient. Without such careful control over all requirements of successful root resective therapy, long-term expectations may be more in line with those of Langer. Unfortunately, the retrospective article by Basten et al is difficult to compare to others because of the small sample size, incorporation of the resected molar into a cross-arch stabilized prosthesis, and lack of periodic periodontal indices.

Potential complications that may occur during root resection procedures are subluxating adjacent teeth, injuring interradicular or proximal bone with the bur, notching a remaining root with the bur, or removing the root but retaining the furcation. Osseous resection surgery is also required following root removal. Backman[62] described four cases of improper or incomplete root resections. He observed continued loss of osseous structure following the amputation. Newell[63] examined 70 root-resected teeth, of which 30% were determined to be inadequate because of remaining furcal ledges or residual roots. Therefore, surgical expertise and experience appear to have significant impact on prognosis.

The restoration of root-resected molar teeth poses additional problems. Typically, there exists a highly variable root configuration in the remaining interfurcal region at the gingival crest, which requires greater attention to detail in tooth preparation. The fluting that is usually present requires adequate, but not excessive, removal of tooth structure for the entire length of the anatomic crown to prevent overcontouring of the final crown and to facilitate proper hygiene procedures. The occlusal table often requires modification from normal form to minimize cantilever forces on the remaining roots, yet to maintain proper proximal contacts. These deviations from usual preparation and laboratory design may tax the inexperienced clinician and dental technician.

Although the prognosis of root resection therapy is unfavorable over time unless the treatment team is highly skilled and can expect optimal patient motivation and maintenance, the decision to remove a furcated molar tooth and replace it with an endosseous implant is not always clear. The initial data from an admittedly small sample of single-molar implants are very favorable; however, the long-term results may not be. Hence the dilemma for the typical treatment team: "When should a furcated molar tooth be extracted and replaced by a dental implant, and when should root resection by employed?" A corollary question is, "Is more or less technical skill required for the successful placement and restoration of a single molar implant versus root resection and crown placement?" Nevins[64] has also discussed this dilemma, specifically the importance of integrating the disciplines of periodontics, endodontics, prosthodontics, and restorative dentistry, and the equal levels of expertise required for successful root resection therapy.

A concomitant consideration is root resection with ostectomy to form positive alveolar architecture. Would removal of bone preclude preservation of adequate alveolar ridge height should the molar tooth be lost in the future? On the other hand, an inferiorly located antral floor may induce the clinician to retain and resect the affected molar rather than augment the antrum to place a dental implant.

When the relative prognosis of one therapeutic option is complicated by additional difficulties, the choice of one over the other becomes clearer. An unfavorable outcome of root resection would be anticipated if one or more of the following problems existed: decreased bone support on all molar roots combined with unfavorable crown-root ratio; a class II or III horizontal furcation involvement combined with a deep vertical component of bone loss, fused roots, endodontically untreatable root destined to be retained, poor root anatomy for remaining roots, inability to maintain proper plaque control, inability to place a proper restoration, and/or marked tooth mobility.

Conversely, an advantageous recipient site for a dental implant would encompass favorable bone quality, adequate bone height and width to accommodate an implant capable of withstanding anticipated occlusal forces, sufficient interdental and interarch distance, noncontributory medical problems or deleterious personal habits, and implant positioning and restoration that would facilitate oral hygiene.

Successful osseointegration seems to be the rule instead of the exception, especially in light of several international, multicenter studies reporting high success rates regardless of implant design and surface characteristics.[65–70] Several studies have suggested that surgical placement and restoration of a missing single molar is not a technically demanding procedure.[71–75] Two of these studies were designed to determine the feasibility of teaching clinical implant therapy to predoctoral dental students. The University of Texas Health Science Center at San Antonio[71] selected students to perform all of the implant surgery, prosthodontics, and maintenance therapy on assigned edentulous and partially edentulous patients. During the first 4 years, 120 implants in 74 patients were placed with no failures. The implication was, that under proper guidance and appropriate case selection, the neophyte can predictably obtain successful implant osseointegration and prosthodontic rehabilitation. At Tufts University School of Dental Medicine,[72] 24 patients were treated with 71 IMZ implants between 1987 and 1991 by senior dental students. Although there were prosthodontic complications, all 71 implants were immobile and the prostheses still functional after the 5-year follow-up period.

Another university-based retrospective study[73] reported on the success rates of 1,263 dental implants placed by 80 different operators whose clinical experience varied widely. Analysis of the outcomes showed a cumulative survival rate of 91.7%. Therefore, favorable outcomes can be achieved with different levels of implant experience.

A related prospective study[74] acknowledged the advantages of single-tooth implants as a prudent treatment option in many cases. A group of dentists in general practice who had no previous experience in implant surgery underwent an intensive training course covering all facets of implant treatment for single missing teeth. Using a system of simplified instrumentation and a strict adherence to protocol, the group placed and restored single-tooth implants, ad modum Brånemark, in a wide range of clinical situations. At the 1-year follow-up period after crown placement, the success rate of treatment compared favorably with results reported from centers using the specialist-team approach to treatment. The study concluded that further consideration should be given to the training of general dentists. Another conclusion of this study was that implant surgery and restorative procedures may not demand extraordinary skill and experience in many clinical situations.

The clinical results of single-tooth implant placement and restoration by general practitioners following 8 days of instruction by experienced oral surgeons, periodontists, and prosthodontists were examined in an analogous report.[75] Four general practitioners performed both the surgery and prosthodontics on patients missing a single tooth. The results of this limited implant therapy favorably corresponded to the treatment outcomes at a specialist clinic.

The treatment of furcated molar teeth includes nonsurgical maintenance, open flap curettage, osseous resection, or root resection. Of primary importance in determining what therapeutic modality is appropriate for a given patient is proper treatment planning. The prognosis will be determined by the individual root anatomy, endodontic complexity, potential occlusal forces, initial mobility, relative skills of the treatment team, and patient compliance. When any of these factors is less than optimal, the literature suggests that long-term retention of the resective molar is questionable.

On the other hand, relevant literature seems to indicate that surgical placement and restoration of single implants is less dependent on the experience or technical abilities of the treatment team. The restoration of dental implants is typified by an abutment or crown connector fabricated in either milled metal or molded plastic designed to certain tolerances. Therefore, the connection of these components should be less problematic than the myriad of natural variations encountered by the periodontist and restorative dentist in their endeavor to rehabilitate the resected molar tooth.

Although direct comparison of treatment outcomes using single implant or resected molar teeth is difficult, general observations can be made. Table 1 lists the reported failure and/or complication rates of

Table 1 Reported Results of Root Resection Therapy

Authors	Resected molars	Failures (%)	Study period (y)
Langer et al[38]	100	38.0	10
Bühler[39]	28	32.1	10
Erpenstein[40]	34	20.6	3
Blomlöf et al[41]	146	32.2	10
Hamp et al[42]*	175	0 (16.1)	5
Klavan[43]*	34	3 (8.8)	1–7
Carnevale et al[44]	488	17.2	3–10
Basten et al[45]**	49	8.0	2–23
Totals†	954	15.9	1–23

*The study period is less than 10 years. The percentages of complications, increasing pocket depths, mobilities, and caries are listed in parentheses.
**All resected molar teeth were incorporated into cross-arch fixed partial prostheses. Only extracted teeth were considered failures.
†Excluding the studies that either covered a period of less than 10 years or did not have extensive fixed splinting (eg, Hamp, Klavan, Basten), the total failure rate was 23.2%.

Table 2 Reported Results of Single Implants Placed into Molar Regions and in Function

Authors	Single molar implants	No. of failures (%)	Study period
Engquist et al[49]	1	0	5 years
Schmitt and Zarb[50]	5	0	1.4–6.6 years
Laney et al[51]	5	0	3 years
Cordioli et al[52]	20	2 (10.0)	0.5–5 years
Haas et al[53]	10	0	1–3 years
Avivi-Arber and Zarb[54]	6	0	1–8 years
Balshi et al[55]	22	0	3 years
Bahat and Handelsman[56]	54	2 (3.7)	3–26 months
Becker and Becker[57]	24	1 (4.3)	2 years
Kemppainen et al[59]	11	0	1 year
Levine et al[60]	94	3 (3.2)	> 6 months
Totals	252	3.6	0.25–8 years

resected molar teeth. They ranged from a low of 11.8% to a high of 38%, for a cumulative rate of 13% (the failure rate increases to 21.2% if only the 10-year studies are included). Single molar crowns supported by dental implants showed failure rates from 0 to 10%, for an average of 3.6% (Table 2). Obviously, caution is required when reviewing the available data. The most obvious caveat is that the total number of reported patients and the time in function of dental implant molar crowns is significantly less than resected molar studies. And, as we have learned, initial success may not necessarily be prognosticatory of future outcomes. Prospective studies of large numbers of single molar implants, using different implant designs and consistent clinical, radiographic, and periodontal indices over a 10-year evaluation period, may eventually address this dilemma.

Summary

1. Molar teeth are at greater risk from periodontal disease.
2. Furcated molars are generally difficult to maintain long-term, having a propensity for early loss because of periodontal disease.
3. Root resection therapy shows poor long-term results unless a high level of expertise is available in all applicable disciplines—periodontal, endodontic, and restorative.
4. The predictability of successful osseointegration with long-term stability is well supported by the literature.
5. Single molar-tooth implant restorations show promising short-term results, although the number of applicable reports are, at present, limited.

6. The apparent successes of dental implant neophytes may indicate that the surgical and restorative procedures are less difficult than management of molar functions vis-à-vis root resective therapy.

References

1. Marshall-Day CD, Skourie KL. A roentgenographic survey of periodontal disease in India. J Am Dent Assoc 1949;39:572.
2. Marshall-Day CD, Septhens RG, Quigley L. Periodontal disease: Prevalence and incidence. J Periodontol 1955;26:185.
3. Ramfjord SP. The periodontal status of boys 11 to 17 years old in Bombay, India. J Periodontol 1961;32:237.
4. Becker BE. Untreated periodontal disease: A longitudinal study. J Periodontol 1979;50:234–244.
5. Payot P, Bickel M, Cimasoni G. Longitudinal quantitative radiodensitometric study of treated and untreated lower molar furcation involvements. J Clin Periodontol 1987;14:8–18.
6. Björn A, Hjort P. Bone loss of furcated mandibular molars. A longitudinal study. J Clin Periodontol 1982;9:402–408.
7. Basaraba N. Furcation invasions. In: Schluger S, Yuodelis R, Page RC, Johnson RH (eds). Periodontal Diseases, 2nd edition. Philadelphia: Lea & Febiger, 1990: 541–559.
8. Bower R. Furcation morphology relative to periodontal treatment. J Periodontol 1979;50:366–374.
9. Everett FB. The intermediate bifurcational ridge: A study of the morphology of the bifurcation of the lower first molar. J Dent Res 1958;37:162.
10. Masters DH. Projection of cervical enamel into molar furcation. J Periodontol 1964;35:49.
11. Rosenberg MM. Furcation involvement: Periodontic, endodontic, and restorative interrelationships. In: Rosenberg MM, Kay HB, Keough BE, Holt RL (eds). Periodontal and Prosthetic Management for Advanced Cases. Chicago: Quintessence, 1988:247.
12. Ramfjord SP, Knowles JW, Morrison EC, Burgett FG, Nissle RR. Results of periodontal therapy related to tooth type. J Periodontol 1980;51:270–273.
13. Nordland P, Garrett S, Kiger R, Vanooteghem R, Hutchens LH, Egelberg J. The effect of plaque control and root debridement in molar teeth. J Clin Periodontol 1987;14:231–236.
14. Hirschfeld L, Wasserman B. A long term survey of tooth loss in 600 treated periodontal patients. J Periodontol 1978;49:225–237.
15. McFall WT. Tooth loss in 100 treated patients with periodontal disease. A long term study. J Periodontol 1982;53:539–549.
16. Pihlstrom B, Oliphant TH, McHugh RB. Molar and nonmolar teeth compared over 6 1/2 years following two methods of periodontal therapy. J Periodontol 1984;55:499–504.
17. Wang H-L, Burget FG, Shyr Y, Ramfjord S. The influence of molar furcation involvement and mobility on future clinical periodontal attachment loss. J Periodontol 1994;65:25–29.
18. Kalkwarf KL, Kaldahl WB, Patil KD. Evaluation of furcation region response to periodontal therapy. J Periodontol 1988;59:794–804.
19. Grbic JT, Lamster IB. Risk indicators for future clinical attachment loss in adult periodontitis. Tooth and site variables. J Periodontol 1992;63:262–269.
20. Ross IF, Thompson RH. A long term study of root retention in the treatment of maxillary molars with furcation involvement. J Periodontol 1978;49:238–244.
21. Farrar JM. Radical and heroic treatment of alveolar abscess by amputation of roots of teeth. Dental Cosmos 1884;26:79.
22. Black GV. In: Litch WF (ed). The American System of Dentistry, vol 1. Philadelphia: Lea Brothers, 1886:990–991.
23. Messinger TF, Orban B. Elimination of periodontal pockets by root amputation. J Periodontol 1954;25:213.
24. Everett FG. Bifurcation involvement. J Oreg Dent Assoc 1959;28:2.
25. Amsterdam M, Rossman SR. Technique of hemisection of multi-rooted teeth. Alpha Omegan 1960;53:4.
26. Hiatt W. Periodontal pocket elimination by combined endodontic-periodontic therapy. Periodontics 1963;1:152.
27. Sternlicht HC. A new approach to the management of multirooted teeth with advanced periodontal disease. J Periodontol 1963;34:150.
28. Amen CR. Hemisection and root amputation. Periodontics 1966;4:197.
29. Basaraba N. Root amputation and tooth hemisection. Dent Clin North Am 1969;13:121.
30. Staffileno H Jr. Surgical management of the furca invasion. Dent Clin North Am 1969;13:103.
31. Bergenholta A. Radectomy of multirooted teeth. J Am Dent Assoc 1972;85:870–876.
32. Glickman I. Clinical Periodontology, 4th edition. Philadelphia: Saunders, 1972:704–707.
33. Grant DA, Stern IB, Everett FG. Orban's Periodontics, 4th edition. St Louis: Mosby, 1972:556–557.
34. Rosenberg MM. Furcation involvement: Periodontic, endodontic, and restorative interrelationships. In: Rosenberg MM, Kay HB, Keough BE, Holt RL (eds). Periodontal and Prosthetic Management for Advanced Cases. Chicago: Quintessence, 1988:272–288.
35. Basaraba N. Furcation invasions. In: Schluger S, Yuodelis R, Page RC, Johnson RH (eds). Periodontal Diseases, 2nd edition. Philadelphia: Lea & Febiger, 1990: 550.
36. Keough B. Root resection. Int J Periodont Rest Dent 1982;2:17–27.
37. Greenstein G. Trisection of maxillary molars: A clinical technique. Compend Contin Educ Dent 1984;5:624–632.
38. Langer B, Stein SD, Wagenberg B. An evaluation of root resections. A ten-year study. J Periodontol 1981;52:719–723.
39. Bühler H. Evaluation of root resected teeth. Results after 10 years. J Clin Periodontol 1988;59:805–810.
40. Erpenstein H. A 3-year study of hemisectioned molars. J Clin Periodontol 1983;10:1–10.
41. Blomlöf L, Jansson L, Appelgren R, Ehnevid H, Lindskog S. Prognosis and mortality of root-resected molars. Int J Periodont Rest Dent 1997;17:191–201.
42. Hamp SE, Nyman S, Lindhe J. Periodontal treatment of multirooted teeth. Results after 5 years. J Clin Periodontol 1975;2:126–135.
43. Klavan B. Clinical observations following root amputation in maxillary molar teeth. J Periodontol 1975;46:1–5.
44. Carnevale G, Di Febo G, Tonelli MP, Mann C, Fuzzi M. A retrospective analysis of the periodontal-prosthetic treatment of molars with interradicular lesions. Int J Periodont Rest Dent 1991;11:188–205.
45. Basten C, Ammons WF, Persson R. Long-term evaluation of root-resected molars: A retrospective study. Int J Periodont Rest Dent 1996;16:207–219.
46. Adell R, Lekholm U, Rockler B, Brånemark P-I. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. Int J Oral Surg 1981;6:387–416.

47. Adell R. Clinical results of osseointegrated implants supporting fixed prosthesis in edentulous jaws. J Prosthet Dent 1983;50:251–254.
48. Adell R. Long-term treatment results. In: Brånemark P-I, Zarb G, Albrektsson T (eds). Tissue-Integrated Prostheses. Chicago: Quintessence, 1985:175–186.
49. Engquist B, Nilson H, Åstrand P. Single-tooth replacement by osseointegrated Brånemark implants. A retrospective study of 82 implants. Clin Oral Implants Res 1995;6:238–245.
50. Schmitt A, Zarb GA. The longitudinal clinical effectiveness of osseointegrated dental implants for single-tooth replacement. Int J Prosthodont 1993;6:197–202.
51. Laney WR, Jemt T, Harris D, Henry PJ, Krogh PHJ, Polizzi G, et al. Osseointegrated implants for single-tooth replacement: Progress from a multicenter prospective study after 3 years. Int J Oral Maxillofac Implants 1994;9:49–54.
52. Cordioli G, Castagna S, Consolati E. Single-tooth implant rehabilitation: A retrospective study of 67 implants. Int J Prosthodont 1994;7:525–531.
53. Haas R, Mensdorf-Pouilly N, Mailath G, Watzek G. Brånemark single tooth implants: A preliminary report of 76 implants. J Prosthet Dent 1995;73:274–279.
54. Avivi-Arber L, Zarb GA. Clinical effectiveness of implant-supported single-tooth replacement: The Toronto study. Int J Oral Maxillofac Implants 1996;11:311–321.
55. Balshi TJ, Hernandez RE, Pryszlak MC, Rangert B. A comparative study of one implant versus two replacing a single molar. Int J Oral Maxillofac Implants 1996;11:372–378.
56. Bahat O, Handelsman M. Use of wide implants and double implants in the posterior jaw: A clinical report. Int J Oral Maxillofac Implants 1996;11:379–386.
57. Becker W, Becker B. Replacement of maxillary and mandibular molars with single endosseous implant restorations: A retrospective study. J Prosthet Dent 1995;74:51–55.
58. Binon P. The role of screws in implant systems. Int J Oral Maxillofac Implants 1994;9(suppl):48–63.
59. Kemppainen P, Eskola S, Ylipaavalniemi P. A comparative prospective clinical study of two single-tooth implants: A preliminary report of 102 implants. J Prosthet Dent 1997;77:382–387.
60. Levine RA, Clem DS, Wilson TG, Higginbottom F, Saunders SL. A multicenter retrospective analysis of the ITI implant system used for single-tooth replacements: Preliminary results at 6 or more months of loading. Int J Oral Maxillofac Implants 1997;12:237–242.
61. Langer B. Root resections revisited. Int J Periodont Rest Dent 1996;16:200–201.
62. Backman K. The incomplete root resection-case presentations. Int J Periodont Rest Dent 1982;2:61–71.
63. Newell DH. The role of the prosthodontist in restoring root-resected molars: A study of 70 molar root resections. J Prosthet Dent 1991;65:7–15.
64. Nevins M. Periodontal prosthesis reconsidered. Int J Prosthodont 1993;6:209–217.
65. Buser D, Weber HP, Brägger U, Balsiger C. Tissue integration of one-stage ITI implants: 3-year results of a longitudinal study with Hollow-Cylinder and Hollow-Screw implants. Int J Oral Maxillofac Implants 1991;6:405–412.
66. Mericske-Stern R. Implants in the edentulous mandible. Clinical experiences with the use of ITI implants in the edentulous mandible: A retrospective after 8 years. Schweiz Monatsschr Zahnmed 1992;102:1214–1227.
67. Wedgewood D, Jennings KJ, Critchlow HA, Watkinson AC, Shepherd JP, Frame JW, et al. Experience with ITI osseointegrated implants at five centres in the UK. Br J Oral Maxillofac Surg 1992;30:377–381.
68. Adell R, Lekholm U, Rockler B, Brånemark P-I. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. Int J Oral Surg 1981;10:387–416.
69. Henry PJ, Bower RC, Wall CD. Rehabilitation of the edentulous mandible with osseointegrated dental implants: 10-year follow-up. Aust Dent J 1995;40:1–9.
70. Fugazzotto PA, Gulbransen HJ, Wheeler SL, Lindsay JA. The use of IMZ osseointegrated implants in partially and completely edentulous patients: Success and failure rates of 2,023 implant cylinders up to 60+ months in function. Int J Oral Maxillofac Implants 1993;8:617–621.
71. Bell FA, Cavazos EJ, Jones AA, Stewart KL. Four-year experience with the placement, restoration, and maintenance of dental implants by dental students. Int J Oral Maxillofac Implants 1994;9:725–731.
72. Cummings J, Arbree NS. Prosthodontic treatment of patients receiving implants by predoctoral students: Five-year follow-up with the IMZ system. J Prosthet Dent 1995;74:56–59.
73. Minsk L, Polson AM, Weisgold A, Rose LF, Sanavi F, Baumgarten H, et al. Outcome failures of endosseous implants from a clinical training center. Compend Contin Educ Dent 1996;17:848–859.
74. Henry PJ, Rosenberg IR, Bills IG, Chan RW, Cohen AC, Halliday KG, et al. Osseointegrated implants for single tooth replacement in general practice: A 1-year report from a multicentre prospective study. Aust Dent J 1995;40:173–181.
75. Andersson B, Odman P, Lindvall AM, Brånemark P-I. Surgical and prosthodontic training of general practitioners for single tooth implants: A study of treatments performed at four general practitioners' offices and at a specialist clinic after 2 years. J Oral Rehabil 1995;22:543–548.