occlusal rest (Fig. 5, *B*), and guiding planes (Fig. 5, C). If there are voids or irregularities, they are filled with monomer and powder with a paint brush.

9. Try-in the removable partial denture (Fig. 6) to ensure a proper adaptation of the resin coping (Fig. 7). The die spacer can be removed from the tooth with a cotton pellet soaked in die spacer thinner. Rinse the tooth several times before cementing the temporary restoration.

10. Transfer the resin coping to the working stone die and finish the margins with wax (Fig. 8). If the surface of the resin coping is not smooth, paint it with a thin layer of liquid wax (Hi-Glass liquid wax glaze, George Taub Products and Fusion Co., Inc., Jersey City, N.J.) before investing and casting. There is little need for an opposing cast because the coping has all the details of the previous cast crown or tooth before preparation; but an opposing model can be used to verify occlusal relationships.

11. Cast, polish, and finish the casting. At the try-in stage, the margins and the occlusion are secured. Finally, adaptation of the RPD to the new crown is appraised (Fig. 9). Cement the crown when all necessary adjustments have been made.

SUMMARY

A procedure to restore an abutment tooth with a complete cast crown to fit an existing RPD has been described.

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Endodontically treated teeth as abutments

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The literature on endodontically treated teeth as abutments for fixed and removable partial dentures is sparse. Reports have been primarily empirical statements because limited clinical studies have been performed.

Some authors†‡ suggest caution with the use of a pulpless tooth as an abutment for a removable partial denture (RPD) especially when it is a rotation point for an extension RPD. Others propose that any endodontically treated tooth can be used as an abutment.[1] It has generally been thought that pulpless teeth require a dowel to reinforce the tooth against fracture.[2-5] However, our own previous research demonstrated that there was no appreciable improvement in clinical success rate with dowel placement for endodontically treated teeth.[6] Several in vitro studies report similar conclusions.[7-9] Furthermore, we reported that pulpless teeth with a traditional custom-tapered cast dowel and core failed more frequently than pulpless teeth without intracoronal reinforcement. Conversely, parallel-sided serrated posts significantly improved the longevity of endodontically treated teeth.[10]

The present clinical investigation compared 1273 endodontically treated teeth as abutments for crowns or primary support for fixed and removable partial dentures. Various methods of intracoronal reinforcement for abutments were examined for the rate and manner of failure.

LITERATURE REVIEW

Numerous articles discussing a variety of factors in abutment selection appear in the literature.[4, 5, 11-13] However, little information is available to evaluate endodontically treated teeth as abutments for fixed partial

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Table I. Comparison of success and failure rate of abutment teeth

	No crown		Crown		FPD		RPD	
	No.	%	No.	%	No.	%	No.	%
Success	160	75.8	833	94.8	116	89.2	41	77.4
Failure	51	24.2	46	5.2	14	10.8	12	22.6
Total	211	16.6	879	69.0	130	10.2	53	4.2
Crown vs. FPD	$\chi^2 = 5.26$; $p < .05$							
Crown vs. RPD	$\chi^2 = 23.1$; $p < .001$							
FPD vs. RPD	$\chi^2 = 3.48$; ns							

dentures (FPD) or RPDs. Many authors feel that "reinforcement" with a dowel is mandatory if these teeth are to be used as FPD or RPD abutments.[13-19] It is felt that pulpless teeth must be adequately reinforced if they are to be subjected to the demands of greater stresses as abutments.[13-19]

No citations could be found in the literature regarding specific considerations in the use of endodontically treated teeth as abutments for RPDs. Kratochvil* circumvents endodontically treated teeth as abutments for RPDs, especially when the tooth serves as a distal-extension partial denture abutment. Krol† concurs with this philosophy if the tooth was endodontically treated more than 10 years earlier.

In evaluating partial denture abutments and the resultant forces, it is necessary to differentiate between entirely tooth-borne and combination tooth-tissue–borne partial dentures.[20, 21] Krol[22] states: "In the fully tooth borne partial denture occlusal stresses are transmitted to bone by way of the periodontal ligament. It functions similarly to a fixed partial denture. The extension base partial denture, however, derives its support from two different tissues, teeth and edentulous ridge each having different degrees of displaceability. This often results in torquing stress on abutment teeth."

Teeth that serve as FPD abutments bear greater stresses in function than single crown abutments.[11-13] Studies have demonstrated that teeth serving as abutments for RPDs receive greater stresses in function than nonabutment teeth.[23-26] Distal-extension partial denture abutment teeth withstand greater stresses than any other abutment tooth.[1, 20, 21, 27-33] These stresses can fracture teeth weakened by endodontic therapy and dowel space preparation.

There is a dearth of research comparing the stresses on endodontically treated teeth that serve as abutments for crowns, FPDs, or RPDs. Although assumptions have been made, there is no indication for greater "reinforcement" of pulpless teeth that act as FPD or RPD abutments.

Nayyar et al.[34] reported that amalgam coronal-radicular cores can be used to restore abutments for FPDs and RPDs. Other investigators suggest that a composite resin core or amalgam core with a prefabricated post is acceptable for single restorations but a cast dowel and core is necessary for abutments.[14-18]

Chan and Bryant[35] found that cast gold dowel and cores required less force before failure occurred, with teeth showing evidence of root fracture. The prefabricated post in combination with amalgam or composite resin exhibited fracture of cores but less evidence of dislodgment or root fracture. These results were in agreement with two other studies.[7, 36]

Perel and Muroff[19] proposed that additional canals must be enlisted to fabricate a multiposted post and core for posterior abutments.

In a longitudinal study of combined periodontal and prosthetic treatment, Nyman and Lindhe[37] evaluated 299 individuals for 5 to 8 years. Of the 332 fixed partial dentures fabricated for the patients, 75% of the abutment teeth that fractured were endodontically treated with posts and were serving as terminal abutments.

Langer et al.[38] evaluated 100 patients 10 years after root resections were performed. A total of 47.4% failed by root fracture, commonly in mandibular molars. The teeth frequently had weakened lateral walls of the root due to endodontic instrumentation and/or post space preparation with questionable post design. In most instances, the breakdown did not become evident until 5 to 10 years after resection. They recommended that only teeth with large roots and large clinical crowns should be used and tipped or isolated mandibular teeth should not be routinely selected for terminal abutments of FPDs.

In summary, empirical statements regarding the use of endodontically treated teeth as abutments for FPDs and RPDs have been made. Conflicting reports in the literature have disconcerted dentists as to the type of coronal-radicular stabilization necessary for the pulpless abutment tooth.

METHODS

Over 6000 patient records of nine general practitioners were reviewed, and teeth with endodontic therapy were selected. Treatment performed for patients was verified radiographically, and teeth were not included in

*Kratochvil, F. J.: Personal communication, 1982.
†Krol, A. J.: Personal communication, 1982.

the study if they were endodontically treated less than 1 year previously. Endodontically treated teeth that failed due to periodontal pathosis or carious involvement were also excluded. Based on these delimitations, 1273 teeth endodontically treated 1 to 25 years prior to the study were reviewed. Data were collected for independent variables listed below.

Type of abutment

Endodontically treated teeth were divided according to the type of abutment: (1) no crown, single tooth; (2) single crown; (3) fixed partial denture abutment; and (4) removable partial denture abutment. In categories two, three, and four, the types of acceptable retainers included three-quarter, seven-eighths, full gold, mesial-occlusal-distal onlay, and ceramometal crowns.

Intracoronal reinforcement

Teeth without intracoronal reinforcement included pin amalgams, pin composite resin fillings, and temporary fillings. Teeth with intracoronal reinforcement were divided into the following categories: (1) tapered cast dowel and core, (2) cast Para-Post and core (Whaledent International, New York, N.Y.) and (3) Para-Post and amalgam or composite resin core.

Manner of failure

Failures of endodontically treated teeth were differentiated into two groups. Group No. 1 teeth were considered restorable because of dislodgment or tooth fracture, and group No. 2 teeth were considered nonrestorable necessitating extraction due to tooth fracture, vertical root fracture, or root perforation.

The records were reviewed for information subsequent to endodontic therapy and the last recorded examination. The definition of clinical success was based on the dentist's last examination.

RESULTS

Table I presents a comparison of the success and failure rates of abutment teeth. The data indicate that the greatest failure rate (24.2%) was associated with pulpless teeth without a crown. A comparison indicated that the failure rate of RPDs (22.6%) was twice that of FPDs (10.2%) and four times that of teeth with crowns (5.2%). Statistical analysis (chi square) revealed that the success rate of crowns was significantly higher than that of RPDs ($p < .001$) and FPDs ($p < .05$). Although there was a difference in the success rate of FPDs and RPDs, chi square analysis did not indicate a statistically significant difference between the two types of abutments.

Table II compares the effects of intracoronal reinforcement on the success and failure rates of abutment teeth. The presence of intracoronal reinforcement did not appreciably influence the success rate of teeth without coronal coverage (no post, 75.4%; post, 87.5%). In single teeth with coronal coverage, the presence of intracoronal reinforcement decreased the success rate (no post, 96.7%; post, 87.5%) and was statistically significant ($p < .01$). Intracoronal reinforcement had a limited effect on the success rate of FPD abutments; however, RPD abutments demonstrated a significant improvement with intracoronal reinforcement ($p < .01$).

Table III presents data associated with success and failure of abutment teeth with different intracoronal reinforcement. Unfortunately, the sample size of this analysis was small; therefore, no statistical comparisons were made. However, trend analysis suggested that the cast Para-Post and the Para-Post and amalgam or composite resin core were more effective methods of intracoronal reinforcement than the tapered cast dowel and core. The failure rate of the tapered cast dowel and core ranged from 12.1% for abutment teeth with crowns to 13.3% for RPDs and 16.7% for FPDs. The failure rate of the cast Para-Post was 0% for single crowns and RPDs, but FPDs were not restored with cast Para-Posts. The failure rate of the Para-Post and amalgam or composite resin core ranged from 2.7% for crowns to 0% for FPDs and RPDs.

Table IV presents a comparison of the manner of failure with the type of abutment tooth, but the sample size was too small for statistical comparison. However, trend analysis suggests a relationship between restorable and nonrestorable tooth fracture and the type of abutment. The percent of restorable tooth fractures for RPDs (13.2%) was twice that of the FPDs (6.2%) and seven times that of the single crowns (1.8%). Similar results were obtained for nonrestorable tooth fractures that required extraction. The rate of nonrestorable tooth fracture for RPDs (7.5%) was twice that of the FPDs (3.1%) and eight times that of the crowns (0.9%). The results were less dramatic for vertical root fracture that required extraction. The rate for RPDs (1.9%) was twice that of the FPDs (0.8%) and three times that of the crowns (0.6%).

DISCUSSION

The findings from this study suggest reevaluation of traditional guidelines for a more flexible approach to a specific situation. The divergence of treatment for pulpless teeth reflects the lack of evidence to substantiate the guidelines. Consider the following two assumptions that have been empirically supported.

Assumption No. 1

"Dowel reinforcement is mandatory in every endodontically treated tooth, especially FPD and RPD abutments." Contrary to the belief that dowel placement is mandatory in all pulpless FPD and RPD abut-

Table II. Comparison of success and failure rate of abutment teeth with and without intracoronal reinforcement

	Type of abutment											
	No crown						Crown					
	Success		Failure		Total		Success		Failure		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
No post	153	75.4	50	24.6	203	96.2	520	96.7	18	3.3	538	61.2
Post	7	87.5	1	12.5	8	3.8	313	91.8	28	8.2	341	38.8
Totals					211	16.6					879	69.0
Chi square analysis					$x^2 = 0.13$						$x^2 = 9.01$	
Significance					NS						$p < .01$	

Table III. Comparison of success and failure rate of abutment teeth with different methods of intracoronal reinforcement*

Type of reinforcement	Crown				FPD				RPD			
	Success		Failure		Success		Failure		Success		Failure	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Tapered cast dowel and core	174	87.9	24	12.1	25	83.3	5	16.7	13	86.7	2	13.3
Cast Para-Post	28	100	0	0	0	0	0	0	10	100	0	0
Para-Post and amalgam or composite resin	109	97.3	3	2.7	10	100	0	0	5	100	0	0

*Chi square analysis was not performed because sample size was too small for certain cells in table.

ments,[13-19] dowel placement demonstrated variable effects on the success rate of abutment teeth. Statistically significant improvement in success rate was not recorded with the placement of a dowel in FPD abutments. In pulpless RPD abutments, dowel placement significantly increased the success rate from 56.5% to 93.3%. This finding may illustrate the difference in functional forces placed on various abutment teeth. Perhaps the FPD retainer behaves similarly to a single crown while the RPD abutment is subjected to many more tensional and torque forces from the RPD.

Hoag and Dwyer's[9] in vitro study tested single crowns on posterior teeth. They reached a similar conclusion when an interlocking stock and cast gold post and core in conjunction with a full crown actually decreased the point of failure.

Similarly, Gelfand et al.[39] found that when full crowns were placed, there was not a difference in failure load of molars regardless of the type of coronal-radicular stabilization.

Assumption No. 2

"A cast dowel and core is the restoration of choice for endodontically treated abutment teeth."[14-18] In comparing different intracoronal reinforcements, the sample size was small and could not be substantiated by statistical tests. However, trend analysis suggested that the tapered cast dowel and core is not necessarily the best treatment. The data indicate that the failure rate of cast Para-Posts and Para-Post and amalgam or composite resin core were considerably lower than the cast dowel and core. Our previous study found that the tapered cast dowel and core had a higher failure rate than teeth with no dowel.[10]

In vitro studies have demonstrated that the tapered cast dowel and core caused more irreversible damage necessitating extraction than did other dowel techniques.[7, 35, 36] These in vitro findings are supported by our earlier research.[10]

The data from Tables II and III suggest that a nondowel technique such as an amalgam coronal-radicular core would suffice for single crowns and FPD abutments;[34] but placement of a dowel and some type of core for retention is necessary for the success of a RPD abutment.

As discussed in a previous article,[10] the manner of failure of a dowel system should be considered when selecting a method of restoration. In this study, the manner of failure was correlated with the type of abutment. As expected from the literature,[1, 11-13, 20, 21, 27-33] trends in the data from Table IV suggest that as one proceeds from a single crown to an FPD and to an RPD there is a concomittant increase in the stresses of function to which the teeth are submitted. This may be interpreted from the trend in the data in which FPDs had three times the rate of restorable and nonrestorable tooth

Type of abutment													
FPD						RPD							
Success		Failure		Total		Success		Failure		Total		Grand total	
No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
80	89.9	9	10.1	89	68.5	13	56.5	10	43.5	23	43.4	853	67.0
36	87.8	5	12.2	41	31.5	28	93.3	2	6.7	30	56.6	420	33.0
				130	10.2					53	4.2	1273	
				$x^2 = 0.01$						$x^2 = 8.11$			
				NS						$p < .01$			

Table IV. Comparison of type of failure with type of abutment

Type of failure	No crown		Crown		FPD		RPD	
	No.	%	No.	%	No.	%	No.	%
Dislodgement (restorable)	—	—	14	1.6	1	0.8	—	
Tooth fracture (restorable)	29	13.7	16	1.8	8	6.2	7	13.2
Tooth fracture (extraction)	12	5.7	8	0.9	4	3.1	4	7.5
Vertical fracture (extraction)	10	4.7	5	0.6	1	0.8	1	1.9
Iatrogenic perforation (extraction)	—	—	3	0.3	—	—	—	—
No failure	160	75.8	833	94.8	116	89.2	41	77.4

fracture than single crowns, and RPDs had seven to eight times that rate. Similarly, the vertical root fracture rate for FPDs was twice that of crowns, and that of RPDs was three times that of crowns.

Studies from the periodontal literature[37,38] report high failure rates associated with abutment teeth that were endodontically treated and prepared for dowels, which corroborates the trends observed in the present study.

The success rate of all endodontically treated RPD abutments was 77.4% compared with FPDs (89.2%) and single crowns (94.8%). These findings support Kratochvil's* practice of avoiding or circumventing pulpless teeth for RPD abutments, especially with distal-extension RPDs.

Since this study did not take into account certain variables in RPD and FPD design and fabrication, additional research is necessary. Variables that were not recorded and may have affected that function of the RPD and stresses on the endodontically treated tooth include (1) rest and retainer design, (2) physiologic adjustment of the RPD framework, (3) the quality of the adaptation of the extension bases, and (4) occlusion. In addition, the length of the span of the FPD was not recorded, and no distinction was made between tooth-borne and distal-extension RPDs. This data can offer further insight into the interaction between functional forces and failure of pulpless abutments.

Studies have shown that the remaining tooth structure that confers strength to an endodontically treated tooth is more crucial than the placement of a dowel.[6,8,10,40-42] Preservation of tooth structure is even more important with pulpless FPD and RPD abutment teeth, which require greater strength than single teeth.

In determining the particular mode of treatment, endodontically treated teeth should be considered individually because one technique will not be applicable to all situations. Factors such as (1) the amount of remaining tooth structure, (2) arch position, (3) the type of abutment, and (4) the functional loads applied should be considered.

Trend analysis suggests the following:

1. The cast Para-Post and core and the Para-Post and amalgam or composite resin core were more effective methods of intracoronal reinforcement for abutment teeth than was the tapered cast dowel and core (Table III).
2. The manner of failure was associated with the type of abutment (Table IV).

CONCLUSIONS

Evaluation of 1273 endodontically treated teeth resulted in the following conclusions, based on statistically significant findings.

1. Abutments for FPDs and RPDs that were endodontically treated had significantly higher failure rates than single crowns (Table I).
2. Coronal-radicular stabilization had a variable affect on abutment teeth. Dowel placement was associ-

*Kratochvil, F. J.: Personal communication, 1982.

ated with a significantly decreased success rate in single crowns. Dowel placement had limited influence on the success rate of FPD abutment teeth. Dowel placement is associated with a significantly higher success rate in RPD abutment teeth (Table II).

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