Assessment of dysplastic dentin in osteogenesis imperfecta and dentinogenesis imperfecta

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Two semiquantitative scoring systems, Clinical Radiographic Score (CRS) and Dysplastic Dentin Score (DDS), were introduced for analyzing degree of dysplastic manifestations in dentin. The utility of both systems was demonstrated in a large material of teeth from patients with dentinogenesis imperfecta (DI) and osteogenesis imperfecta (OI). Twenty teeth from healthy controls, 81 teeth from 40 patients with OI, and 18 teeth with DI without OI (DI type II) were examined. The degree of dysplasia was correlated with type and form of OI and type of DI. The median DDS did not differ between DI associated with OI (DI type I) and DI type II. DDS in OI patients without clinical signs of DI was above that of control teeth. Both circumpulpal and mantle dentin showed increased DDS, although circumpulpal dentin was more severely affected. The median DDS was highest for the most severe type of non-lethal OI (type III). DDS increased significantly with form (severity) of OI. A significant association between DDS and CRS was found, although diagnosis of DI in less severe cases was not possible based on radiographic or clinical signs alone. Thus, the DDS system proved valuable when the CRS system based on radiographic/clinical manifestations failed, the most significant finding being subclinical histological manifestations of DI in patients with OI but without clinical or radiographic signs of DI. These subtle dysplastic changes are most likely an expression of genetic disturbances associated with OI and should not be diagnosed as DI, but rather be termed histologic manifestations of dysplastic dentin associated with OI. □ *Histology; inherited disorders; pathology; teeth*

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Disturbances in dentin formation can be attributed to either defective mineralization of the dentin matrix resulting in interglobular dentin (non-calcified dentin matrix) or disturbances in the formation, composition, or organization of the dentin matrix resulting in dysplastic dentin (1). Interglobular dentin is most often a sequel to acquired disturbances caused by for example nutritional deficiencies or infections. In contrast, dysplastic dentin refers to inherited conditions, dentinogenesis imperfecta (DI), that may present as single trait disorders or in association with osteogenesis imperfecta (OI) (2, 3). OI is a genetic disorder of connective tissue caused by mutations in either the COL1A1 or COL1A2 genes that encode the pro-α1 and pro-α2 chains of type I collagen (4, 5), the major protein of the organic matrix in bone and dentin. OI is most commonly divided into four types on the basis of clinical, radiographic, and genetic findings (Table 1) (4, 6, 7); however, it can also be divided into mild, moderate, and severe forms depending on patient motility (8, 9).

In patients with DI, the teeth are characterized by discoloration which ranges from a greyish-blue to brown hue. The enamel is often dislodged, exposing the soft dysplastic dentin, which can lead to rapid attrition. The primary teeth are more severely affected than the permanent. Radiographically, the teeth show short roots, bulbous crowns that constrict at the cervix, and pulpal obliteration. DI may present in patients without any other signs of disability. This condition is called DI type II (3) and has been attributed to autosomal dominant mutations in the dentin sialophosphoprotein (DSPP) gene, encoding two dentin-specific non-collagenous matrix proteins, dentin sialoprotein, DSP, and phosphoprotein, DPP (10, 11). A clinically and radiographically similar dental condition is also often present in patients with OI, which most likely reflects the fact that type I collagen is the main organic component in both dentin and bone (12). The dental aberration associated with OI has been designated DI type I (3). The reported prevalence of DI in patients with OI has been reported to be 28%–73% (8, 13). The incidence of DI is highest in OI types III and IV (8, 9, 13–15). In OI type I there is a great discrepancy in the reported incidence, varying from 8% to 40% (8, 15).

The clinical, radiographic, and histological manifestations of DI types I and II are similar, although the expression of DI type I is more varied (3, 9, 16). Histologically, the dentin is characterized by a dysplastic appearance with amorphous areas void of dentin tubules, irregular dentinal tubules, embedded cells, and occasionally interglobular dentin (1, 14, 17–20).

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Table 1. Classification of osteogenesis imperfecta, modified from Byers (4), Sillence et al. (6), and Levin et al. (7)

OI type	DI	Clinical features	Inheritance*
IA	–	Normal or mild short stature	AD
IB	+	Little or no deformity Blue sclerae Hearing loss common	
II	?	Extremely severe osseous fragility, stillbirth or death in the newborn period and beaded ribs	AD (*de novo* mutations) AR (rare)
III	+/–	Very short stature Progressively deforming bones, usually with moderate deformity at birth Scleral hue varies, often lightening with age Hearing loss less common than in Type I	AD AR (uncommon)
IVA	–	Variably short stature	AD
IVB	+	Mild to moderate bone deformity Normal sclerae Hearing loss less common than in Type I	

* AD = autosomal dominant; AR = autosomal recessive.

There is considerable variation in the degree of dysplastic manifestations within the dentin in patients with DI (21). A quantitative histological analysis of dentin aberrations with a scoring system has been developed by Siar (22), allowing comparison of the degree of dysplasia between patients. However, most of the previous studies on dentin in patients with DI have been qualitative and based on examinations of multiple teeth from a rather small number of patients. Hence, the present investigation was undertaken in an attempt to systematically assess the degree of variability in dysplastic features in dentin in a large number of patients with DI types I and II and in patients with OI without clinical signs of DI. Semiquantitative scoring systems for assessing clinical appearance and radiographs as well as the degree of dysplastic manifestations in dentin were developed. The aim of the study was to investigate possible correlations between degree of dysplasia and type and form of OI and type of DI as well as between clinical/radiographic and microscopic manifestations of DI.

Materials and Methods

Patients

Fifty-eight consecutively referred patients were included in the investigation: 40 with OI and 18 with DI type II. Thirty-eight patients with OI were recruited from the National OI team at the Astrid Lindgren Children's Hospital (Karolinska Hospital, Stockholm), 13 patients with DI type II and 1 patient with OI from the Department of Pediatric Dentistry at Eastmaninstitutet (Stockholm), and 1 patient with OI and 5 patients with DI type II from other centres. Of the 40 patients with OI, 24 showed no clinical or radiographic signs of DI, whereas DI was clinically verified in 16 patients. In addition, 20 healthy subjects were included as controls.

The 52 patients referred to the National OI team or treated at the Eastmaninstitutet were examined clinically and radiographically, including panoramic radiographs in 41 patients. Clinical photographs documented tooth color and malocclusions. Radiographs were available for examination from the 6 remaining patients, in addition to clinical photographs of 3 patients. A Clinical Radiographic Score (CRS) was created, where score 1 characterized neither clinical nor radiographic signs of DI, score 2 only subtle signs, score 3 either clinical or radiographic clear signs, and score 4 clear clinical and radiographic signs.

The patients with OI were classified by the National OI team, to which one of the authors (BM) belongs, according to type (6) and form (8, 9) (Table 2). Patients with the mild form have full mobility, patients with the moderate form

Table 2. Presence or absence of detectable DI by clinical and/or radiographic criteria in the patients with different types and forms of OI

	Form of OI							
	Mild ($n = 21$)		Moderate ($n = 8$)		Severe ($n = 11$)		Total ($n = 40$)	
Type of OI	DI	no DI	DI	no DI	DI	no DI	DI	no DI
I	4	15	3	1	–	2	7	18
III	–	–	–	–	5	2	5	2
IV	1	1	1	3	2	–	4	4
Total	5	16	4	4	7	4	16 (40%)	24 (60%)

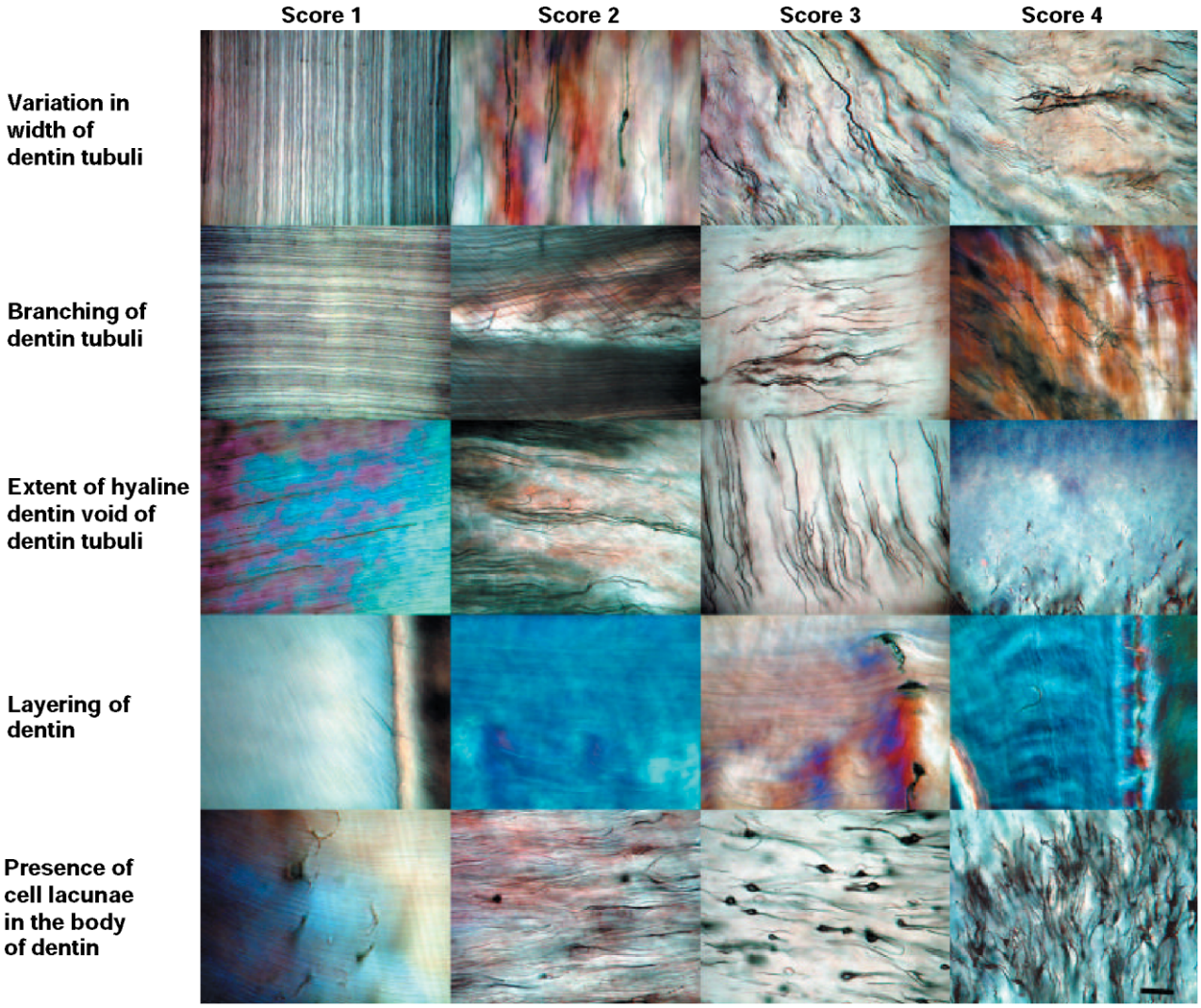

Fig. 1. Examples of dysplastic manifestations for the 5 criteria: branching of dentin tubules, variations in the width of dentin tubules, presence of hyaline dentin void of dentin tubules, layering of dentin, and presence of cell lacunae in the body of dentin, ranging from no change (score 1) to severe changes (score 4). The sections are viewed with interference contrast optics (Nomarski). Bar = 10 μm.

can walk short distances but require a wheelchair for longer distances, and patients with the severe form have a constant need for a wheelchair.

The study protocol was approved by the local ethics committee at the Karolinska Institute.

Investigational tooth material

Eighty-one teeth were collected from the 58 patients. One mother and her daughter with OI type IB and 3 siblings from one family with DI type II were the only related patients. Fifteen permanent and 35 primary teeth extracted for orthodontic or other therapeutic reasons, with complete crowns and at least one-third of the roots, were available for examination. In addition, 31 exfoliated primary teeth with crowns only were collected. From 2 patients with OI and 3 with DI type II, both primary and permanent teeth were collected. From 11 patients, more than 1 tooth with crowns only was available for examination (29 crowns). From the 20 healthy controls younger than 20 years of age, 10 primary and 10 permanent teeth were collected. The collected teeth had been stored in formalin, water/saline or dry. Distribution between the teeth in the different types of storage was equal.

Histotechnical preparation

The teeth collected for preparation of ground sections were dehydrated in a graded series of ethanol, rinsed in chloroform, and embedded in resin (LR White Resin, London Resin Company Ltd., London, UK). Polymeriza-

Table 3. Distribution of investigational material (teeth from patients with OI and DI type I, patients with OI without DI, and patients with DI type II)

Diagnosis	Patients *n*	Primary teeth, crowns and roots *n*	Primary teeth, crowns only *n*	Permanent teeth *n*	Total *n*
OI with DI	16*	11	2	4	17
OI without DI	24*	12	8	5	25
DI type II	18†	12	3	6	21
Controls	20	10		10	20
Total	78	45	13	25	83

* One primary and 1 permanent tooth from 1 patient were examined.
† One primary and 1 permanent tooth examined from each of 3 patients.

tion was completed at 60°C for 48 h. The plastic blocks were mounted on plastic slides with Technovite 7210 VLC (Kulzer & Co. GmbH, Wehrheim, Germany). Specimens were cut longitudinally in a bucco-lingual direction in an Exact cutting unit and grounded with an Exact Micro-Grinder, using a diamond abrasive paper (1200), to a thickness of between 80 and 110 µm, according to the Exakt system (EXAKT Apparatebau, Norderstedt, Germany). One central section from each tooth was examined in a Leitz Aristoplan (Ernst Leitz, Wetzlar GmbH, Wetzlar, Germany) under normal transmitted and polarized light as well as with interference contrast optics and under incident ultraviolet light when appropriate.

Histological assessment

Ground sections were assessed semiquantitatively for dysplastic manifestations in the dentin. The following 5 criteria were graded for each tooth according to a 4-step scale ranging from no dysplasia (score 1) to severe dysplasia (score 4): branching of dentin tubules, variations in the width of dentin tubules, presence of hyaline dentin void of dentin tubules, layering of dentin, and presence of cell lacunae and duct-like structures in the body of dentin (Fig. 1).

The body of dentin was divided into 4 areas: circumpulpal and mantle dentin in the crown and in the root. Each area was assessed separately as described above. The total sum of scores of all criteria and areas was calculated for each tooth and designated the dysplastic dentin score (DDS). Thus, the minimum total sum for teeth with both crowns and roots was 20, and the maximum sum 80. Hence, a total score of 20 represents a structurally normal tooth. In investigations of the relationship between DDS and type and form of OI and type of DI, only teeth with at least one-third of the root available were included.

The authors performed blinded evaluation of the sections on two separate occasions. Circumpulpal and mantle dentines were distinguished from each other using polarized light microscopy at crossed polars. The distinction was possible because of differences in collagen fiber orientation between the two tissues despite their close proximity. The fibers in the mantle dentin are radially oriented while those of the circumpulpal dentine are oriented perpendicular to the long axes of the dentin tubules creating different birefringent patterns (23).

Statistical evaluation

Comparisons of DDS between control subjects and patients with OI but without DI, and patients with DI type I and patients with DI type II, and comparisons of DDS between control subjects and patients with different types of OI were performed with the Mann-Whitney U test. The DDS in crowns and roots, circumpulpal and mantle dentin in the crowns, and circumpulpal and mantle dentin in the roots were compared using the Wilcoxon matched-pairs Test. The association between DDS in the different types of OI was analyzed with the Kruskal Wallis test. The associations between DDS in the different forms of OI, and between DDS and CRS were analyzed with the Spearman rank correlation coefficient test. The *P* value to indicate a significant deviation from the null hypothesis was set at 0.05. All data were analyzed using Statistica v. 5.5 (Statsoft, Scandinavia AB, Uppsala, Sweden).

Results

The sum of DDS after the blinded evaluation differed in 8 teeth (8.9%). The difference, which was found in the branching or variation in the width of dentin tubules, never exceeded one score point. In one of the control teeth, branching in the apical circumpulpal dentin and variation in the width of dentin tubules were noted, resulting in a DDS of 22. Determination of DDS for

Table 4. DDS for patients ($n = 5$) from whom both primary and permanent teeth were obtained

	DDS			
	Primary		Permanent	
Diagnosis	Crown	Root	Crown	Root
OI with DI	24	26	32	32
OI without DI	10	–	10	22
DI type II	22	–	14	21
DI type II	20	21	10	26
DI type II	20	20	20	22

multiple teeth from the same patient and same dentition showed only negligible variations, never exceeding 1 score point (29 teeth from 11 patients). When a discrepancy between DDS of the crown and the root was present, root dentin always showed the higher DDS. Therefore, only the available tooth with most tooth substance from each patient and each dentition was included in the further evaluation. Thus, the material for further analyses consisted of 63 teeth from 58 patients (Table 3).

General findings

Consistently, branching and variations in the width of the dentin tubules were the most prevalent abnormalities followed by the presence of hyaline dentin void of tubules and cell lacunae. Layering of dentin was seen in only the most severely affected patients with DI type I and in patients with DI type II. In patients with no clinical or radiographic signs of DI but with a mild form of OI type I, only 4 teeth had a DDS of 20, and an additional 5 teeth had a DDS below 24.

There was a clear cut-off in DDS (DDS = 23) between teeth collected from healthy controls and patients with DI or OI. The median DDS did not differ between DI type I (DDS = 39) and type II (DDS = 38). The DDS was above the cut-off limit in OI patients without clinical signs of DI.

The circumpulpal dentin was more dysplastic than the mantle dentin in both crowns and roots. In crowns, where DDS theoretically ranges from 5 to 20 in the mantle and circumpulpal dentin, respectively, the median DDS of the circumpulpal dentin was 10 (range 5–20) and of the mantle dentin 6 (range 5–14) ($n = 50$, $P < 0.001$). In roots, the median DDS of the circumpulpal dentin was 11 (range 5–20) and of the mantle dentin 7 (range 5–15) ($n = 50$, $P < 0.001$). In 9 of 50 teeth, no dysplastic manifestations were noted in the root mantle dentin. In teeth from patients with a mild form of OI ($n = 15$), the median DDS in the whole mantle dentin, which ranges theoretically from 10 to 40, was 10 (range 10–14); with a moderate form ($n = 7$) 12 (range 10–26); and with a severe form ($n = 10$) 15 (range 11–29) ($P = 0.001$). A post-hoc analysis using the Mann-Whitney U test and compensating for three comparisons, i.e. setting $P = 0.016$ to indicate a significant deviation from the null hypothesis, revealed a significant difference only between the mild and severe forms ($P < 0.001$).

The DDS in the collected primary and permanent teeth did not differ. The median DDS of the primary teeth ($n = 42$) was 27 (range 20–58), while the median DDS of the permanent teeth ($n = 25$) was 26 (range 20–64), NS. Both permanent and primary teeth were available from 5 patients (Table 4). In this limited material, no significant conclusion regarding the severity of changes in the primary as compared to the permanent dentition could be drawn. It should be noted that the 3 roots in the primary teeth were not intact and may thus be given too low a DDS.

The association between DDS and CRS was significant at $r_s = 0.81$. However, within the group of patients and control subjects with CRS 1 (no clinical/radiographic signs of DI), detection of dysplastic dentinal changes was only possible using DDS assessment. Within this group ($n = 36$), DDS varied between 20 and 32. When excluding CRS 1, no correlation was found ($r_s = 0.33$, $P = 0.26$) (Fig. 2).

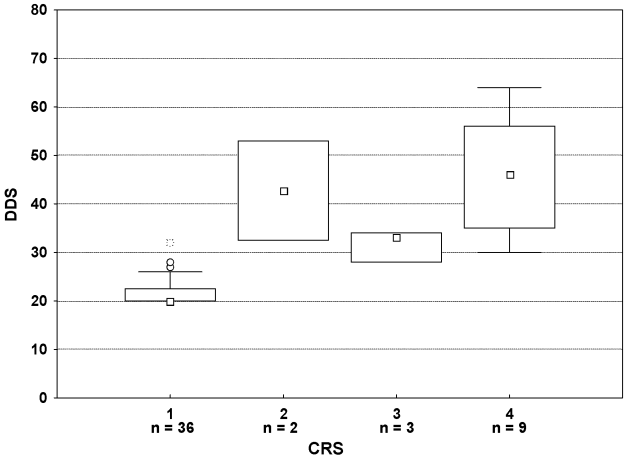

Fig. 2. Association between CRS and DDS ($n = 50$). Clinical photographs not available in 1 of the 31 patients. Small central squares denote median values, solid surrounding box denotes 25%–75% intervals, and brackets denote min-max values. Outliers and extremes are marked with circles and one extreme with a cross (r_s including CRS 1 = 0.81, $P > 0.000$, r_s excluding CRS 1 = 0.33, $P = 0.26$).

Teeth from patients with OI and DI (DI type I)

Seventeen teeth from 16 patients with DI type I were available. Both crowns and roots were examined in 15 teeth, whereas only crowns from 2 teeth. The median DDS was 39 (range 27–64). The DDS was similar for crown and root dentin, never differing by more than 3 DDS units. In all teeth, branching of the dentin tubules and variation in the width were observed in the circumpulpal dentin. Hyaline dentin void of dentin tubules was present in all but 1 tooth and cell lacunae in 11 teeth. Layering of dentin was found in only 5 teeth.

Teeth from patients with OI but without DI

Twenty-five teeth from 24 patients with OI but without clinical and radiographic signs of DI were examined. Both crowns and roots were available from 17 teeth, and only crowns in 8. Among teeth with roots available, 9 exhibited a DDS of 23 or less, i.e. within the range observed in teeth from healthy controls. The median DDS was 23 (range 20–32). In 4 teeth, the crown dentin was normal, whereas dysplastic dentin was clearly visible in the roots. In the remaining 4 teeth, dysplastic findings were present in both crown and root dentin with a higher DDS towards the apex. In 9 teeth, dysplastic dentin was found in the mantle dentin in the root. Hyaline dentin void of dentin tubules and cell lacunae was only seen in the root dentin. No teeth

Table 5. Distribution of primary and permanent teeth according to form of OI and presence or absence of DI

	Mild form of OI		Moderate form of OI		Severe form of OI		Total	
	Primary *n*	Permanent *n*	Primary *n*	Permanent *n*	Primary *n*	Permanent *n*	Primary *n*	Permanent *n*
DI	4	1	2	1	4	2	10	4
No DI	8	2	2	2	2	1	12	5
Total	12	3	4	3	6	3	22	9

exhibited layering of dentin.Two of the 8 teeth from which only crowns were available exhibited branching of dentin tubules and occasional cell lacunae.

Teeth from patients with DI type II

Twenty-one teeth from 18 patients with DI type II were examined. Both crowns and roots were available from 18 teeth and only crowns from 3. The median DDS was 38 in teeth with both crowns and roots (range 30–52). Branching and variation in the width of dentin tubules were seen in all teeth. The DDS for the crown and root dentin was identical in 10 teeth. In 7 teeth, the DDS in the root was 1–7 points higher than in the crown. In one permanent tooth, the crown dentin was normal, while the DDS in the root was 26.

Association between severity (form) of OI and DDS

Any association between form of OI and DDS was analyzed in patients with various forms of OI. The material consisted of 42 teeth from 40 patients with OI and 20 control teeth (Table 3). Eleven of the teeth from the patients with OI were excluded from further analyses; 10 teeth with crowns only and one primary tooth from a patient from whom one permanent tooth was also available. Thus, the OI material consisted of 31 teeth from 31 patients (Table 5). There was a clear relationship between the DDS and the severity (form) of OI: the more severe the form of OI, the higher the DDS (Fig. 3).

Association between type of OI and DDS

The same material consisting of 31 teeth from 31 patients with OI was further analyzed for any putative association between DDS and type of OI (Fig. 4). All investigated types of OI showed an increased DDS as compared to control teeth, and the DDS varied according to type of OI. Teeth from patients with OI type III had a higher DDS than teeth from patients with OI type I. The difference in DDS between teeth from patients with OI type I and type IV and between teeth from patients with OI type III and IV did not reach statistical significance.

Association between type of DI and DDS

The association between type of DI and DDS was investigated in patients with OI but without clinically detectable DI, patients with OI and DI type I, and patients

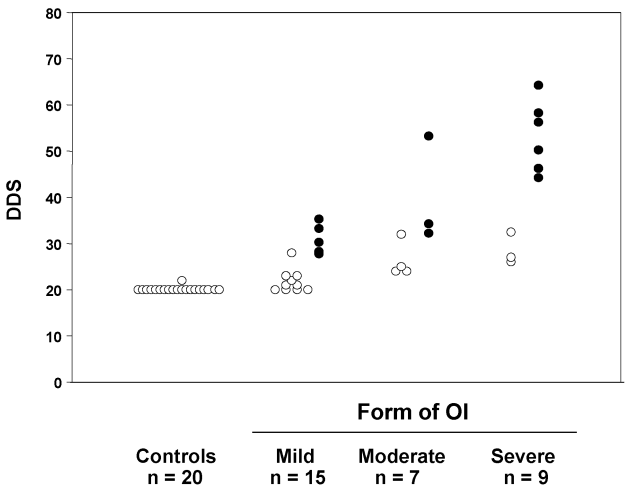

Fig. 3. Association between form of OI and DDS. Filled circles indicate patients with DI type I and empty circles patients without clinical signs of DI (r_s (including controls) = 0.86, r_s (excluding controls) = 0.65, $P < 0.001$). The highest DDS for patients without clinical/radiographic DI was 32.

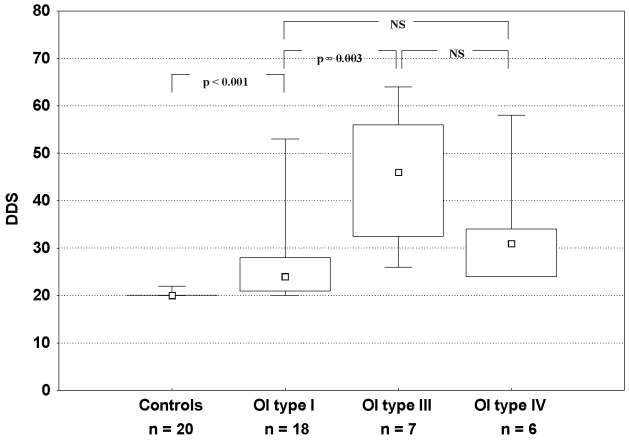

Fig. 4. Association between type of OI and DDS. Small central squares denote median values, solid surrounding box denotes 25%–75% intervals, and brackets denote min-max values. The distribution between primary and permanent teeth was 10/10 in control subjects, in patients with OI type I 13/5, in patients with OI type III 4/3, and in patients with OI type IV 5/1. All types of OI had higher DDS compared to control teeth ($P < 0.001$). The DDS varied according to type of OI ($P = 0.005$).

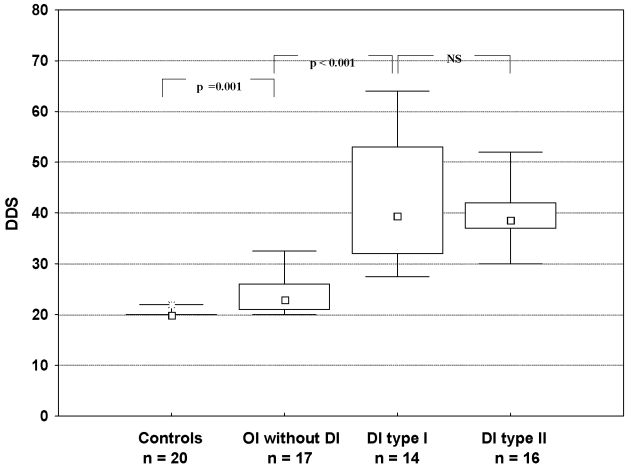

Fig. 5. Association between teeth from patients with OI without DI, with DI type I and DI type II and DDS. Small central squares denote median value, solid surrounding box denotes 25%–75% intervals, and brackets denote min-max values. The distribution between primary and permanent teeth in control subjects was 10/10, in patients with OI without DI 12/5, in patients with DI type I 10/4, and in patients with DI type II 10/6.

with DI type II (Fig. 5). The material consisted of 83 teeth from 40 patients with OI, 18 patients with DI type II, and 20 healthy controls (Table 3). Eleven of the teeth from the patients with OI were excluded from further analyses; 10 teeth with crowns only and 1 primary tooth from a patient from whom one permanent tooth was available. Five of the teeth from the patients with DI type II were excluded: 3 with crowns only and 2 primary teeth from patients from whom 1 permanent tooth was also available. Even teeth from patients with OI but without clinical or radiographic signs of DI had an increased DDS compared to controls. Nevertheless, DDS in patients with OI but without clinical signs of DI showed a relatively small overlap with DDS in patients with OI and DI type I. There was no significant difference between the DDS recorded in DI types I and II, although there was a greater variation in DDS among patients with DI type I.

Discussion

In the present investigation, two scoring systems (DDS and CRS) were introduced to describe the diversity of dysplastic manifestations in the dentin in patients with different types and forms of OI with and without DI type I and patients with DI type II. Branching and variation in the width can be observed in normal teeth, as well as layering of dentin in rare cases, while hyaline dentin or cell lacunae and duct-like structures are never found in control subjects. Thus, in order not to erroneously diagnose healthy teeth as dysplastic, a DDS ranging from 20 to 23 was considered as normal. The major findings were that: 1) DDS in teeth from the same patient and dentition showed only minor variations; 2) when a discrepancy in the DDS between root and crown was present, DDS in the root was consistently higher; 3) DDS was higher in circumpulpal dentin than in mantle dentin, but dysplastic manfestations were common in mantle dentin as well; 4) DDS varied according to *type and form* of OI; 5) DDS was higher in some patients with OI without clinical or radiological signs of DI than in the controls; 6) there was no significant difference between the DDS in DI types I and II, although there was a greater variation in DDS in type I; 7) a significant association between DDS and CRS was found.

Previous histological studies of dentin abnormalities in DI type II and in OI have been based on small numbers of patients, several teeth from the same patients, or exfoliated primary teeth with physiological root resorption (24–27). As previously reported by others (14), we found only minor variations in teeth from the same dentition and included therefore only one tooth from each patient and dentition. Furthermore, DDS was higher in the root than in the crown. This emphasized the need to examine both crown and root, and not only exfoliated primary teeth, especially in patients with mild forms of OI.

Among earlier studies on dysplastic dentin the following have employed light microscopy and polarized light microscopy (1, 24, 27–33), scanning electron microscopy (25, 26, 31, 34), transmission electron microscopy (32, 35, 36), microradiography (24, 29, 37, 38) or immunohistochemistry and immunoelectron microscopy (39–41). In the present study, the specimens were ground and examined with light microscopy. This allowed examination of not only the surface of the dentin sections but also structures within the sections. Discrete abnormalities in mantle dentin are better visualized with light microscopy than with scanning electron microscopy (28). Furthermore, clinical pathologists most often work with light microscopy as their primary tool, and a diagnostic system based on light microscopic findings thus allows an investigation to be performed in a routine setting.

Previously, a microscopic scoring system for analysis of dysplastic dentin was developed by Siar and applied to the crowns of 3 permanent teeth from patients with OI and 6 primary and 3 permanent teeth from patients with DI type II (22). The crown dentin was divided into 3 zones, and the relative abundance of dentinal tubules, atubular dentin, and canals or clefts was registered in each zone. In the present study, a more detailed semiquantitative method for evaluating dysplastic manifestations in dentin was introduced. The wide variation of DDS (20–64) in the material and the reproducibility of the scoring procedure enabled comparison of DDS among multiple teeth from the same patient and among teeth from different patients as well as analysis of the relationship between DDS and other clinical findings.

The mantle dentin has been reported to be normal in teeth from patients with DI regardless of type by some investigators (14, 17, 27, 42, 43), whereas distinct abnormalities have been found by others (25, 26). Although the

dysplastic manifestations in the mantle dentin were subtle in many teeth and not a consistent finding, the present study has shown that mantle dentin may show dysplastic manifestations in patients suffering from OI and DI type II. The dysplastic manifestations in the mantle dentin increased with severity of OI.

DDS was related to both type and form of OI. Thus, teeth from patients with OI type III had a higher DDS than teeth from patients with other types, and an increasing severity of the disease was associated with an increasing DDS. Eight of 17 teeth from patients with OI without clinical and radiological signs of DI showed a higher DDS than control teeth. These teeth thus had clearly but not severely dysplastic dentin, despite a clinically normal appearance. This finding is in concordance with other investigations (26, 32, 43, 44). Furthermore, a significant association was found between DDS and CRS.

In conclusion, we have introduced two scoring systems (DDS and CRS) for analyzing the degree of dysplastic manifestations in dentin and demonstrated the utility of both systems in a large material of teeth from patients with DI and OI. Specifically, the DDS system proved valuable when the CRS system based on clinical/radiographic manifestations failed, the most significant finding being subclinical histological manifestations of DI in patients with OI but without clinical or radiographic signs of DI. Thus, these subtle dysplastic changes are most likely an expression of genetic disturbances associated with OI and should not be diagnosed as DI, but rather be termed histologic manifestations of dysplastic dentin associated with OI.

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