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ORIGINAL ARTICLE

Hypocalcified type of amelogenesis imperfecta in a large family: clinical, radiographic, and histological findings, associated dento-facial anomalies, and resulting treatment load

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Abstract

Objective. The purpose of this study was to report on the clinical, radiographic, and histological dental findings and the resulting treatment load in a five-generation family with amelogenesis imperfecta (AI). ***Material and methods.*** Thirteen affected and 15 unaffected individuals were examined clinically and radiographically. In addition, four exfoliated deciduous teeth were examined by scanning electron microscopy and microradiography. ***Results.*** The mode of inheritance of AI was autosomal-dominant. At eruption, most of the tooth enamel was yellow, lacking translucency, and prone to gradual loss in subjects with AI. Post-eruptive breakdown of enamel was extensive in accordance with the histological observations of hypomineralized and porous enamel. Extensive enamel loss and discoloration were observed in older affected individuals. The treatment need had been extensive: 76.2% of the total number of teeth present in affected individuals had been treated with partial or full coverage compared to 1.7% of the teeth in unaffected relatives. Unaffected individuals had more endodontically treated teeth than AI-affected relatives. Adjunctive findings, e.g. tooth agenesis, tooth impaction, pulp stones, enlarged follicular space, and taurodontism, were rare in both groups. ***Conclusions.*** Affected family members had the hypocalcified type of AI, which is characterized by severe hypomineralization, extensive post-eruptive loss, and discoloration of the enamel. Adjunctive findings were rare. Individuals with the hypocalcified type of AI have an extensive restorative treatment load compared to unaffected relatives.

Key Words: *Amelogenesis imperfecta, autosomal dominant, enamel, phenotype*

Introduction

Amelogenesis imperfecta (AI) is a hereditary dental anomaly affecting the enamel of the deciduous and permanent dentition [1]. It is characterized by extensive clinical diversity and several different classification systems have been suggested [2]. The literature on AI mainly consists of case reports and thus the lack of systematic reporting of clinical and radiographic findings has hampered the full appreciation of its manifestation, its associated dento-facial anomalies, and the resulting treatment load [3].

The purpose of the present study was to report on the clinical, radiographic, and histological dental findings, associated dento-facial anomalies, and the resulting treatment load in a large five-generation family with AI.

Material and methods

Study population

The probands of the study were two brothers with AI referred to the Centre for Oral Health in Rare Medical Conditions at Aarhus University Hospital, Denmark. The family of the probands consisted of 41 members belonging to five generations. As some of the anomalies described in association with AI are known to be genetically determined, and as patterns of dental treatment must be assumed to be similar

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among family members, affected as well as unaffected family members were included in the study. Five of the 41 family members had died before the study period, among which one was reported as having AI (the great-grandmother of the two probands). Thus, 36 family members were invited to participate in the investigations, and 28 (77.7%) agreed to do so. Thirteen affected (8 F and 5 M; mean age 39.0 years, SD 25.3) and 15 unaffected (8 F and 7 M; mean age 41.9, SD 19.2) individuals were examined. The research protocol was approved by the regional ethics committee (protocol no. 20050017). Written information about the project was sent to all family members. The participants or guardians gave written informed consent before entering the study.

Clinical examination

The clinical examination was carried out by three of the authors (H.G., G.H., and D.H.) consulting each other when questions arose over clinical findings. The clinical examination included recording of the teeth present in the mouth, color and transparency of the enamel, characteristics of the enamel surface, and post-eruptive enamel breakdown. In addition, previous dental treatment was recorded, as were dentures if present. The vertical overbite was measured in millimeters (mm) using a steel calliper and in accordance with the method of Bjørk et al. [4]. Edentulous individuals were interviewed about the condition of their natural teeth prior to extraction.

Radiographic examination

In individuals with teeth present in the oral cavity, a full-mouth periapical survey consisting of 14 conventional film radiographs was performed. In edentulous individuals, a digital standard panoramic radiograph was taken. If impacted teeth were observed on the panoramic image, digital periapical radiographs of these teeth were obtained. Two of the authors (H.H. and D.H.) jointly examined all radiographs for changes in the dental hard tissues and for associated conditions. Concerning the dental hard tissues, reduced thickness of the enamel, reduced contrast between enamel and dentine, and lack of calcified hard tissue (clinically appearing as "moth-eaten") were assessed. In addition, dental anomalies (tooth agenesis, supernumerary teeth, tooth impaction, delayed eruption, root resorption, pulp stone, pulp obliteration, enlarged follicular space and taurodontism) were recorded as well as root-filled teeth and teeth with periapical lesions.

Two unaffected family members did not participate in the radiographic examination, one due to pregnancy and one to low age (a one-year-old child). The radiographic examination thus comprised 13 affected individuals (mean number of recordable teeth: 25.6, SD 8.6) and 13 unaffected (mean number of recordable teeth: 25.5, SD 7.8). Four individuals in the affected group were edentulous. In addition, one of the affected had only two teeth, both of which were impacted.

Scanning electron microscopy

Four exfoliated deciduous teeth were collected from two AI-affected boys (IV:12 and IV:13) (Figure 1). The teeth were treated with a 5% sodium hypochlorite solution, followed by spraying with water, washing in 0.12 M PBS, drying with compressed air, and dehydration in graded ethanol solutions. The teeth were mounted on metal stubs using silver glue and sputter-coated with platinum and carbon by a standard evaporation technique. The specimens were studied in a CamScan scanning electron microscope (model MaXim 2040, EnVac; Cambridge, UK). The evaluation of enamel morphology was based on photomicrographs at 25 to 25,000-fold magnifications.

Microradiography

After scanning electron microscopy, the specimens were sectioned using a Leitz saw microtome no. 1600 and sagittal ground sections were obtained at 60–80 μm. Contact microradiographs were exposed on KODAK MIN-REV plates. The X-ray source was a Balteau OE650, no. K70522 with a tungsten anode and a beryllium window. The X-rays, emitted at 20 kV and 20 mA, were filtered through a 20 μm Ni filter. The distance between the photographic plate and the focus was 20–30 cm.

Classification of AI types

The type of AI was determined according to the criteria by Witkop [5].

Results

The pattern of inheritance

Allegedly, the great-grandmother of the probands had "yellow teeth", indicating AI. She was one of four siblings (2 M and 2 F), and was probably the only one affected. The pedigree of the family (Figure 1) indicates autosomal-dominant inheritance. X-linked inheritance can be excluded because of father-to-son transmission of the disease (III:9 to IV:9).

Description of affected teeth

Newly erupted premolars and canines had fairly normal outer contours of the tooth crowns, and the thickness of the enamel in the gingival part was normal. In the occlusal part of the crowns,

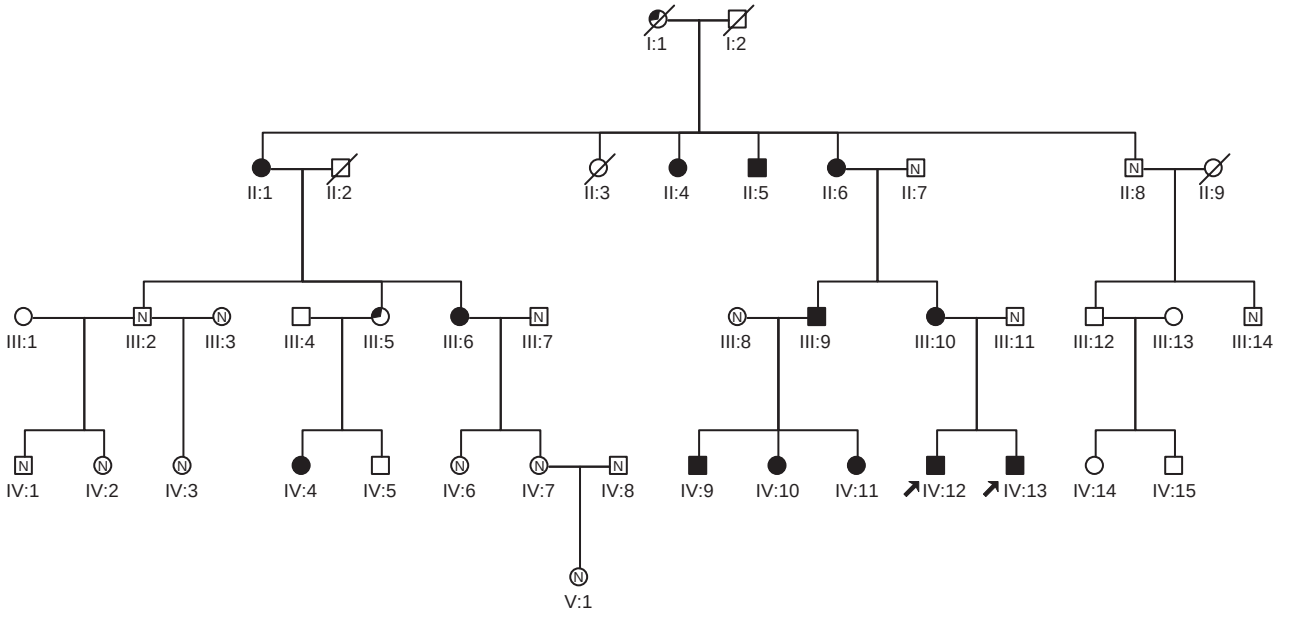

Figure 1. A pedigree chart of the five-generation family. Males are marked with squares and females with circles. Filled symbols: affected individuals. Clear symbols with "N": included, not affected. Partially filled symbols: individuals reported to be affected, not included. Clear symbols: individuals reported to be unaffected, not included. Arrows: the probands of the study. Symbols with crossing: deceased.

considerable post-eruptive breakdown had taken place (Figure 2). The longer the post-eruptive period, the more extensive the breakdown. Newly erupted molar crowns had a tent-like appearance, with imaginary "tent poles" forming the cusp tips and loosely supporting the enamel layer as if it was

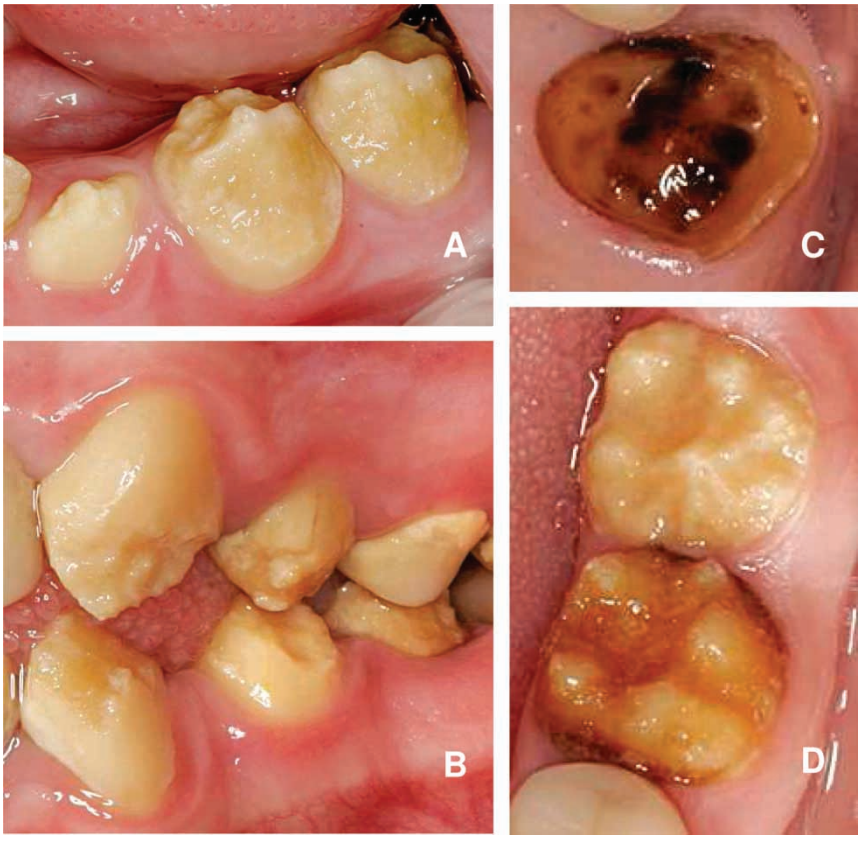

Figure 2. Clinical photographs of permanent teeth in AI-affected individuals. The photographs show extensive discoloration of the molars, severe loss of enamel, and the cervical enamel that is better preserved than enamel at the more incisal part of the tooth crowns. A. Lower left canine, 1st premolar, and 2nd premolar in a 12-year-old boy (IV:12) with yellow-brown enamel, extensive loss of tooth substance, and preserved enamel cervically. B. Teeth with a "moth-eaten appearance" in a 12-year-old girl (IV:11). C. Upper left 2nd molar with cusp tips smoothened off in a 28-year-old female (IV:4). D. Lower left 1st and 2nd molars in a 14-year-old girl (IV:10). Pointed cusp tips are visible on the molars. Numbers in parentheses refer to ID numbers in Figure 1.

tent canvas. The enamel surface of the molar crown in younger individuals was irregular. In a 28-year-old female (Figure 1, IV:4), the surfaces of the molar crown were regular and smooth, as if the tip of the cusps had been lost, reducing the height of the crown, and resulting in a flat occlusal surface exposing dentine without enamel layer (Figure 2C). However, a layer of enamel, apparently of normal thickness, was present at the level of the gingival border. The color of the enamel of newly erupted teeth was light-yellow with whitish, cloud-like patterns, and the normal translucency of enamel was absent (Figure 2A, D). Fractured enamel was yellow or brownish, while exposed dentine was brown with some almost black patches spread across the surface.

The phenotypic variation was limited among five AI-affected family members with uncovered permanent canines, premolars, or molars available for clinical assessment. In all four individuals with assessable canines or premolars, all teeth had rough surfaces and areas with lack of enamel occlusally. In half of these individuals, teeth had preserved enamel gingivally. Concerning molars, all such teeth, in all but one out of five individuals, had rough surfaces and preserved cusp tips. All teeth in all five AI-affected individuals had preserved enamel cervically. In addition, two out of five individuals had calculus deposits.

In individuals affected by AI, the radiographs showed reduced enamel thickness in nearly half, and, in those, the feature was found in up to 50% of assessable teeth (Table II). Reduced contrast between enamel and dentine was found in the vast majority of affected individuals (7 out of 8 (87.5%)), among whom the feature was found in the majority of assessable teeth (63–100%). The corresponding figures for lack of calcified hard tissue ("moth-eaten" appearance) were seven individuals and 42–100%, respectively. The mean proportions with features, reduced thickness of enamel, reduced contrast between enamel and dentine, and lack of calcified hard tissue were 17.9%, 79.3%, and 65.9%, respectively (Table II).

Histologically, the shedded deciduous AI-affected teeth demonstrated a rough surface and coronal attrition (Figure 3A, B). Microradiographs of ground sections demonstrated abraded grooves where incisal enamel had been chipped off, while enamel was found in full thickness near the cemento-enamel junction (Figure 3C–E). The contrast between enamel and dentine was low on conventional radiographs, however some contrast could be observed on the more sensitive microradiographs. Scanning electron micrographs also demonstrated cervical steps where the occlusal enamel had been chipped off. Scanning electron micrography at higher magnifications revealed that the remaining enamel surface had grooves characterized by a coral-like structure spread in between putatively normal enamel ridges. These formations were found at the center of the depressions and were surrounded by seemingly normal enamel (Figure 4).

Associated dental anomalies

No aberrations in the number of teeth (agenesis or supernumerary teeth) were found in any of the family members. Impaction was observed in three individuals among the AI-affected as well as in three of the unaffected family members (2.6% and 1.8% of the teeth, respectively). Resorption of the roots of permanent teeth was not observed in either of the two groups. Pulp stones were found in four (1.4%) of the teeth in the affected individuals and in three teeth (0.9%) of the unaffected individuals. Pulp obliteration was not found in any of the affected individuals and in one of the unaffected individuals. An enlarged follicular space around an unerupted permanent tooth was observed in two of the affected

Table I. Dental treatment status of eight dentated AI-affected members of the family. Of a total of 13 AI-affected individuals, 5 were edentulous. Age, dentition, and dental treatment status in permanent teeth at the time of the clinical examination are reported.

Person ID[a]	Age	No. and type of teeth	No. of teeth with fillings	No. of teeth with partial or full coverage of crowns
III:9	41	28 PT	0	28 FC
III:10	38	27 PT	0	1 B, 25 FC
IV:4	28	22 PT	0	20 FC
IV:9	16	27 PT	1	4 SSC, 18 CC
IV:10	14	24 PT, 3 dt	0	2 SSC, 16 CC
IV:11	12	24 PT	0	11 CC
IV:12	12	24 PT, 2 dt	0	4 SSC, 7 CC
IV:13	9	12 PT, 11 dt	0	4 SSC, 4 CC

[a]ID numbers in Figure 1.
PT: permanent teeth.
dt: deciduous teeth.
FC: full crown (metal or ceramic).
B: fixed bridge; two abutment teeth and one pontic.
CC: composite crown or composite veneer.
SSC: stainless steel crown.

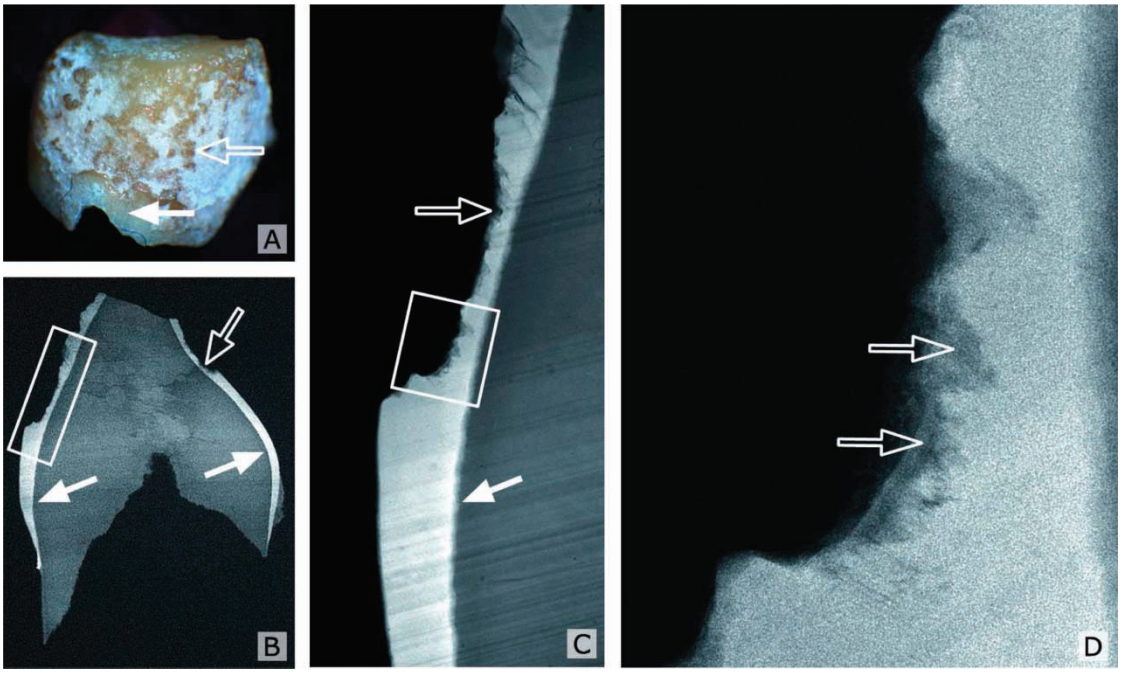

Figure 3. Exfoliated deciduous canines from an AI-affected boy (IV:12). A. Photograph of a lower canine (labial view). The enamel has full thickness in the apical part (filled arrow), but extensive loss can be seen in the coronal part (open arrow). B–D. Microradiographs of sagittal ground sections from an upper canine. Boxed areas are magnified in subsequent figures. B. Overview of the canine showing two incisal areas where the enamel has chipped off (open arrows). At the cervical part of the crown, a well-defined step in the enamel indicates the border between areas with full enamel thickness (filled arrow) and areas with post-eruptive breakdown of enamel (open arrows).

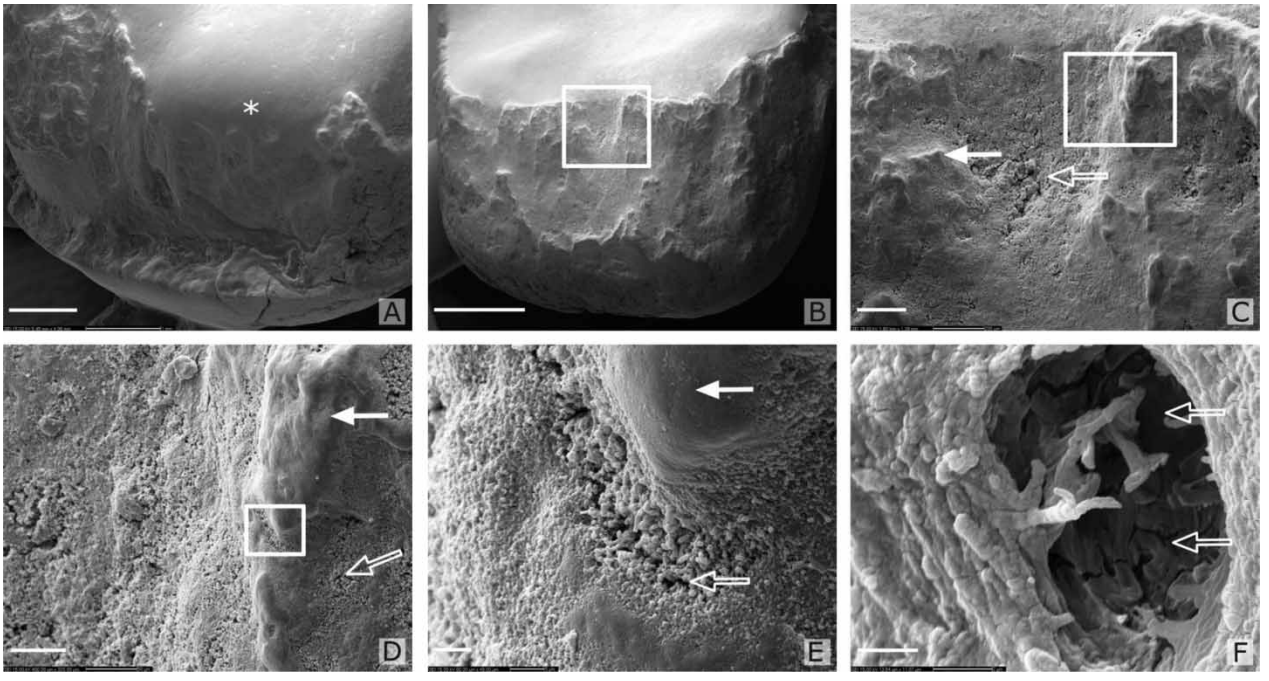

Figure 4. Scanning electron micrographs of exfoliated deciduous molar from an AI-affected boy (IV:13). The enamel demonstrates extensive disorganization with irregular structure and a rough surface. A. A cervical step in the enamel is demonstrated where the occlusal enamel had been chipped off by post-eruptive breakdown. The fracture lines to residual enamel apparently follow the lines of Hunter-Schreger. Boxed areas in enamel surface are magnified in subsequent figures (B–F). The enamel surface demonstrates hypomineralized regions. A coral-like structure (open arrow) is observed at the bottom of the depressions. Surrounding crests demonstrate putatively normal enamel (filled arrow). A. Occlusal restoration (asterisk). Bars in (A): 900 μm, (B): 1800 μm, (C): 200 μm, (D): 50 μm, (E): 5 μm, and (F): 2 μm.

individuals (9 teeth), but in none of the unaffected family members. Taurodontism was not found in either of the two groups.

Vertical overbite

In the affected group, two individuals had open bite grade one [4], overbite <0 mm, while this trait was not present in any of the unaffected family members.

Dental treatment status

All five edentulous individuals (48, 63, 69, 76, and 81 years of age, respectively), one of them from generation III, were AI-affected, and had worn full upper and lower dentures since childhood. Only two of the unaffected individuals (72 and 75 years of age, respectively, from generation II) wore dentures (partial) and had 18 and 6 permanent teeth present, respectively. The mean number of permanent teeth present in the affected individuals was 14.7 (SD 11.9); the corresponding number in the unaffected group was 25.2 (SD 7.3). Eight dentated individuals were AI-affected, and all had received extensive restorative care (Table I). A total of 144 (76.2%) of the 189 permanent teeth present in these eight affected individuals were treated with partial or full coverage (veneers or crowns), while only three teeth had conventional fillings. In the group of unaffected individuals, 6 of 353 (1.7%) teeth were treated with full coverage while 133 teeth (37.7%) had conventional fillings. The one-year-old unaffected girl from generation V was excluded from these calculations.

The AI-affected individuals had in total one (0.5%) endodontically treated tooth, and one tooth (0.5%) had a periapical lesion. In the group of unaffected individuals, 10 (3%) of the assessed teeth belonging to 6 individuals had received endodontic treatment, and 3 (0.9%) teeth in 3 individuals had a periapical lesion.

AI-type

The enamel in affected individuals showed the clinical and radiographic characteristics of hypocalcified AI (type IIIA) according to the classification system of Witkop [5].

Discussion

The present study reports dental findings of members of a five-generation family with autosomal-dominant, hypocalcified AI. In individuals affected by AI, the enamel was yellow, lacking translucency, and prone to gradual post-eruptive breakdown. The dental treatment load of the affected individuals was heavy compared with the unaffected individuals. Adjunctive findings were rare and limited to few eruption-related problems.

Clinical examination of the enamel in the affected individuals was complicated by the loss of teeth and by coverage of the vast majority of the tooth crowns. This also complicated the radiographic examination and the possibility of detecting, e.g., pulp stones and taurodontism. However, the number of untreated teeth available for clinical examination was sufficient to determine the type of AI. Although retrospective information from previous dental records could have provided more detailed information on various aspects of treatment, this was not available from all members of the family.

The radiographic characteristics of the enamel revealed reduced contrast between enamel and dentine in the majority of the affected teeth. Microradiographs with a high contrast sensitivity and resolution confirmed the findings on periapical radiographs but demonstrated in addition remaining contrast between the residual thin enamel and dentine. The observations of reduced enamel-dentine contrast are indicative of a low content of minerals in the enamel, and this is likely to be

Table II. Radiographic findings in dental hard tissues in 9 out of 13 AI-affected members of the family. Four affected members had no teeth visible on radiographs. Numbers of permanent teeth with reduced thickness of enamel, reduced contrast between enamel and dentine, and lack of calcified hard tissue are reported.

Person ID[a]	No. of teeth visible on radiographs	Reduced thickness of enamel No./No.[b] (%)	Reduced contrast enamel/dentine No./No.[b] (%)	Lack of calcified hard tissue[c] No./No.[b] (%)
I:1	2	0/2 (0)	2/2 (100)	2/2 (100)
III:9	28	–	–	–
III:10	29	1/2 (50)	2/2 (100)	1/2 (50)
IV:4	24	0/2 (0)	0/2 (0)	1/2 (50)
IV:9	32	0/19 (0)	12/19 (63)	5/12 (42)
IV:10	29	2/18 (11)	16/18 (89)	10/11 (91)
IV:11	28	6/17 (35)	15/17 (88)	18/18 (100)
IV:12	30	9/19 (47)	18/19 (94)	15/16 (94)
IV:13	28	0/22 (0)	22/22 (100)	0/20 (0)

[a]ID numbers in Figure 1.
[b]No./No.: number of teeth with the clinical characteristic/number of teeth available for assessment in the specific category (%). Some teeth could not be assessed; for example, because of restorations or technical limitations of the radiographs.
[c]Irregular borders of the tooth crown indicating reduced amount of calcified hard tissue. The designation corresponds to what is called "moth-eaten appearance" at clinical examinations.

one of the reasons for post-eruptive breakdown. Together with the post-eruptive breakdown, the clinical examination revealed that the enamel was more discolored with increasing age, presumably due to uptake of colored agents from food and drinks.

Histological examination confirmed the clinical impression of hypomineralized enamel. The porous enamel corresponded to the observation of locally increased interprismatic space and decreased formation of crystals. Such changes are expected, in turn, to increase the risk of attrition, cracks, and smoothing of putative cracks in the enamel surface. However, the cervical enamel and the tip of the cusps were relatively resistant to enamel loss. The fact that the cervical part of the enamel is not likely to be subject to the occlusal forces may, in part, account for the relatively intact enamel in the cervical regions. Whether differences in the degree of hypomineralization of the enamel at various parts of the tooth surface might explain the variation in enamel breakdown could not be determined. Whether the thin surface zone of hypermineralized enamel [6] might play a 'protective' role in maintaining the cervical enamel intact due to the relatively lower enamel thickness as a whole in this region could not be determined. This interpretation is based solely on histological examination of deciduous teeth, as no permanent teeth were available for histological analysis.

Surprisingly, the tip of the cusps was also relatively resistant to enamel loss in spite of the fact that masticatory forces on occluding tooth surfaces, including the cusps, are expected to be high. However, evidence actually suggests greater stiffness and high fracture resistance of human cusps due to the increased thickness of enamel [7]. Observed enamel fracture lines, located both cervically and on the side of the crowns, seem primarily to be intrinsic and follow the inclined or perpendicular lines of Hunter-Schreger. However, in human cusp enamel the bands of Hunter-Schreger are expected to be arranged horizontally [8] and spirally [9], with the same orientation of crystals in prismatic and interprismatic regions [10]. Therefore, it could be speculated that hypomineralized enamel on tips of the cusps may be more resistant to masticatory forces and enamel loss to some extent due to increased thickness and strength of the enamel [7].

The clinical characteristics of the enamel correspond well with Witkop's description of hypocalcified AI (yellow color and changes in color after eruption, friability and loss of enamel by attrition, calculus deposit in young individuals, tendency to open bite), while the reduction in radiopacity of the enamel seemed to be less than described by Witkop [5]. Data regarding dental hypersensitivity was not collected systematically, but hypersensitivity was occasionally reported by AI-affected subjects during the clinical examinations.

In contrast to what has been reported in the literature [3], surprisingly few adjunctive findings to AI were seen in the family. This may reflect differences in adjunctive findings between different types of AI, but it may also be due to differences in diagnostic criteria for taurodontism, for example [11–15]. Agreement on the diagnostic criteria for dental anomalies is needed as well as more studies with complete reporting of adjunctive findings in different types of AI. An enlarged follicular space was found in the affected group and this could be indicative of eruptional disturbances. On the other hand, very few teeth were impacted – a feature also found in the unaffected group. Other studies have reported an enlarged follicular space adjunctive to AI [16–18], as well as impaction or delayed eruption [19–22]. Thus, monitoring of dental eruption might also be relevant in the hypocalcified type of AI.

The treatment pattern seen in this family mirrors the changes in treatment philosophy from a very radical philosophy, often involving extraction and full dentures, to extensive restorative treatment over the past 60 years. The youngest generation has benefited from modern restorative care, where treatment deploys the acid-etch technique and composite materials. As seen in several of the AI-affected family members, the burden of dental treatment was considerable. In spite of extensive restorative treatment, the number of endodontically treated teeth was low in the affected individuals compared with their unaffected relatives. This could indicate that affected family members were more concerned about early dental treatment than were the unaffected members.

More reports with comprehensive reporting of clinical and radiographic findings, adjunctive findings, and treatment load are needed if the full heterogeneity in the manifestation of AI is to be appreciated.

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