Representing Intracoranal Tooth Restorations in the Ontology for Oral Health and Disease

William Duncan[1,*], Titus Schleyer[2] and Alan Ruttenberg[3]
[1] Department of Philosophy, University at Buffalo, Buffalo, NY, USA
[2] Center for Biomedical Informatics, Regenstrief Institute, Inc., Indianapolis, IN, USA
[3] School of Dental Medicine, University at Buffalo, Buffalo, NY, USA

ABSTRACT

The Ontologies in Oral Health and Diseases project aims to support dental research by allowing researchers to more easily access information contained in electronic dental record systems. The Oral Health and Disease Ontology (OHD) is at the core of the project. This ontology contains, among others, terms for the diagnosis and treatment of dental maladies. One key area of dental research involves issues surrounding tooth restorations. In this paper, we explain the basic methodology for developing the OHD, demonstrate how an intracoronal tooth restoration is represented in the OHD, and discuss some of the ways in which the OHD enables information sharing amongst researchers.

1 INTRODUCTION

Most electronic dental record (EDR) systems store information in a relational database. Clinical researchers wishing to conduct research using this information, however, are often hindered by poor documentation, inconsistent encoding of information, and complex relationships between the database's tables. While consulting with IT professionals or EDR vendors may address these issues, the mechanisms created for accessing the EDR's information are tailored to a specific EDR's database schema. This makes sharing information contained in multiple EDR systems very difficult.

The Ontologies in Oral Health and Diseases project (Ruttenberg, Duncan, Schleyer, Haendel, & Tornai, 2012) aims overcome the problem of data sharing by providing clinical researchers with a general ontological representation of the information in an EDR system. At the core of this project is the Oral Health and Disease Ontology (OHD)[1]. This ontology contains terms, among others, for the "diag-

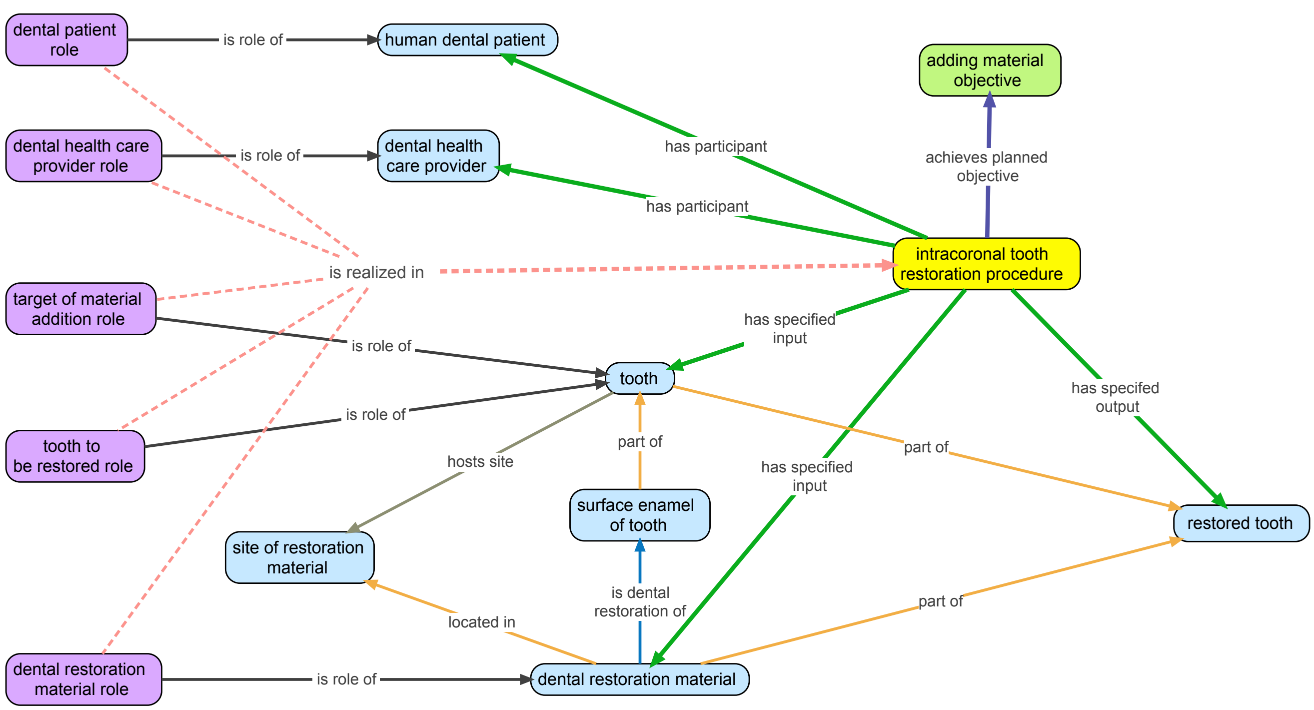

Fig 1. An instance diagram showing how an intracoronal tooth restoration procedure is represented in the Ontology of Oral Health and Disease. The boxes represent instances of the classes named inside the box, and arrows represent relations between the instances.

* To whom correspondence should be addressed: wdduncan@gmail.com

[1] The development version of OHD is available at http://purl.obolibrary.org/obo/ohd/dev/ohd.owl

nosis and treatment of dental maladies", such as root canals, tooth decay, tooth extractions, crowns, fillings, inlays, onlays, etc. Using OHD terms, information from multiple EDRs can be translated into OWL 2 (W3C OWL Working Group, 2012) statements, and stored in a semantic database, such as OWLIM (Ontotext). SPARQL (Prud'Hommeaux & Seaborne, 2008) queries can then be used to extract information for analysis.

Although the scope of the OHD is quite broad, we have targeted representing intracoronal restorations, more commonly called 'fillings', as a starting point. Our reasons for starting with these restorations are twofold. First, since intracoronal restorations are performed quite often, most EDR systems will contain data about them. A general representation of intracoronal restorations will thus provide a means to create large data sets about these restorations from multiple EDR systems. Second, in order to represent intracoronal restorations, we have to develop representations for dental procedures, oral diseases, and anatomy. This lays the groundwork for representing a broad range of dental procedures, such as root canals and crowns. In this paper, we explain the basic methodology for developing the OHD, demonstrate how an intracoronal tooth restoration is represented in the OHD, and, in the last section, discuss some of the ways in which the OHD enables information sharing amongst researchers.

2 DEVELOPMENT OF THE OHD

Development of the OHD consisted of three main tasks. The first task was to gain a general understanding of dental procedures, oral diseases, and tooth anatomy. This involved consulting dental school textbooks and practicing dentists. We then focused our research on intracoronal restorations. This research identified seven types of entities involved in an intracoronal tooth restoration: (1) tooth, (2) surface of tooth, (3) dental restoration material, (4) site into which the material is placed, (5) dental patient, (6) dental care provider, and (7) tooth restoration process. The representation of these entities is discussed in the next section.

Our second task was to develop a general sketch of how to represent the entities identified in the first task in the Basic Formal Ontology[2] (BFO) (P. Grenon, 2003; P. Grenon, Smith, B., Goldberg, L., 2004). The following list of BFO's basic categories aids in understanding the outline of the ontology:

(1) **Continuant**: An entity that persists through time. For example, material objects, such teeth, persist through time.

(2) **Dependent Continuant**: A continuant that depends on another continuant. For example, the shape of a tooth depends on that tooth, but there is no shape of a tooth without a tooth.

(3) **Role**: A dependent continuant that characterizes how the bearer of the role behaves in some special circumstance. For example, you realize the role of being a dental patient when you undergo a dental exam.

(4) **Material Entity**: A three-dimensional entity with mass, such as a tooth.

(5) **Process**: Something that happens.

Once we had a general sketch of the entities using BFO's terms, we searched for terms in other OBO ontologies (B. Smith et al., 2007), based on BFO, that we could reuse by either importing the terms directly or creating more specific terms. A partial list of the ontologies used are listed in the following table:

Ontology	Terms reused or specialized
Ontology for General Medical Science (OGMS) (Scheuermann, Ceusters, & Smith, 2009)	entities related to health care; e.g., patient role, health care provider role, visit, disorder, symptom
Foundational Model of Anatomy ontology (FMA) (Rosse & Jr, 2007)	anatomical descriptions of teeth, tooth surfaces, jaws, etc.
Ontology for Biomedical Investigations (OBI) (Brinkman et al., 2010)	properties to relate processes to entities; e.g., relating a restoration material to the restoration procedure
Information Artifact Ontology (IAO)(Ruttenberg et al., 2013)	representation of information about entities in the dental health care domain; e.g., billing codes, goals of dental procedures

INTRACORONAL TOOTH RESTORATIONS IN THE OHD

Figure 1 (below) illustrates how an intracoronal tooth restoration is represented in the OHD. Each box represents an instance of the class named in the box, and arrows between the boxes represent relations. In the remainder of this section, we discuss the classes (in **bold** font) and relations (in *italic* font) used in the OHD to represent an intracoronal tooth restoration.

We represent teeth by using FMA's **tooth** class and its subclasses, such as **incisor tooth**, **canine tooth** etc. In the version of the FMA we worked with initially, tooth surfaces were defined as boundaries of the tooth (i.e., the two dimensional surface that bounds the outside of the tooth). These terms were unsuitable for representing the three-dimensional portion of enamel into which the restoration

[2] Currently, we are using BFO version 1.1.

material (i.e., the filling) is placed.[3] We therefore defined the class **surface enamel of tooth**. Subsequently, based on our feedback, the FMA has incorporated these terms (Mejino, 2012).

We define **intracoronal tooth restoration procedure** as subclass of **dental procedure**, itself a subclass of OGMS's **health care process**. It is defined as:

> A **tooth restoration procedure** in which the **site** that **dental restoration material** is added to is inside a **crown of tooth**.

A **tooth restoration procedure** is, in turn, defined as

> A **dental procedure** in which parts of a tooth that have been lost due to disease or other causes is replaced by **dental restoration material** in order to reform the **tooth** and reestablish anatomical and functional form and health.

A **health care process** is a subclass of OBI's **planned process** class. Instances of **planned processes** aim at achieving some goal, and one goal of an intracoronal restoration is to place restoration material in the crown of the tooth. This goal is represented using OBI's **adding material objective** class. The site (or space) into which the restoration is placed is represented in the OHD as an instance of **site of restoration material**, a specialization of BFO's **site** class. To represent the final outcome of an intracoronal tooth restoration process, we define a **restored tooth** as the sum of (i.e., has as parts) the tooth and the restoration material.

Dental restoration material is a subclass of OBI's **processed material**. **Processed materials** are materials that have been modified as part of a **planned process**. To differentiate instances of **dental restoration material**, we define a **dental restoration material role** that captures that the material is capable of being used in the restoration process. In this case, the restoration material is being used to restore the tooth to structural and functional integrity. We differentiate between the patients on which restorations are performed and dental providers who perform restorations by defining **dental patient role** and **dental health care provider role** to characterize the way that each person is involved in a tooth restoration process. As another example, dental patient role is defined as:

> A **patient role** borne by a toothed organism and is realized in a **dental procedure**

To represent spatial relationships, we use the Relation Ontology's (RO) (Barry Smith et al., 2005) *part of, has part* and *located in* relations. For example, all instances of **surface enamel of tooth** are *part of* some instance of **tooth**.

[3] In some cases the restoration material may also be placed in both the enamel and dentin, or only in the dentin.

RO's *has participant* relation is a general way of relating processes to the entities that partake in them. When the process is an instance of **planned process**, OBI's *has specified input* and *has specified output* relations are used represent that an entity's participation is specified as part of the process' plan. Since an instance of **intracoronal tooth restoration procedure** is an instance of **planned process**, we employ the *has specified input* relation to represent that some tooth and portion of restoration material are specified as part of the plan for performing the restoration. The instance of **dental restoration material** specified as input to the intracoronal tooth restoration process is then related ro the site (or space) in the tooth that it occupies by the *hosts site* relation. The *has specified output* relation represents that the **restored tooth** is specified as an outcome of the plan.

OBI's *is role of* relation is used to relate roles that characterize an entity's potential behavior to the entities that bear them. The *is realized in* relation is then used to relate roles to the processes in which the behavior is exhibited. For example, some portion of amalgam (a common type of restoration material) bears the role of being an **intracoronal restoration material**. This role is then realized when the amalgam is placed in a tooth during an **intracoronal tooth restoration procedure**.

Goals of an **intracoronal tooth restoration procedure** are related to that process using OBI's *achieves planned objective* relation. In the figure, we show the adding material objective, which is a (correct) consequence placing our procedure in OBI's hierarchy. There are, of course, other goals, and representing them will be part of our future work. To represent that an instance of **dental restoration material** is restoring a particular tooth surface, we define the *is dental restoration of* relation in the OHD. This shortcut relation was requested by our dental experts.

DISCUSSION OF INFORMATION SHARING

As noted in the introduction, the aim of the Ontologies in Oral Health and Diseases project is to allow researchers to more easily access oral health information. The OHD facilitates this in at least two important of ways. First, the structuring of entities in the OHD can be more easily understood than information often found in an EDR database. The documentation of the terms are as queriable as the data itself, making structure discovery possible, and the structure more directly depicts what the dentist is familiar with. For example in the OHD, a tooth surface is represented as being *part of* a tooth, and a tooth is represented as being a *part of* a jaw. Thus, by transitivity of the *part of* relation, an automated reasoner can easily infer/verify that a tooth surface is part of a jaw, contributing to the ease of making queries and the testing the integrity of the data overall.

In contrast to this, one EDR system we examined stored information about teeth and surfaces in two character arrays. In these arrays, a '1' or a '0' in each index of the array denoted information about a particular tooth or surface. The tooth character array consisted of fifty-five characters (i.e., '1' or '0'). The first thirty-two positions were used for information about secondary (i.e., adult) teeth. The next twenty positions were used for information about primary (i.e., baby) teeth. And the last three positions were used for information about supernumerary (i.e., extra) teeth. If a restorative procedure was performed on a tooth, the corresponding character position in the tooth array would be changed to a '1'. For example, to record that a filling was placed in a patient's upper-right second molar, the second position in the array would be changed to a '1'. None of this structure was clearly documented. This idiosyncratic way of representing teeth is not typically communicated, and thus creates an obstacle for researchers wishing to share or access it. To implement an automated reasoner over this data, a computer program must be developed that is specific to each implementation. This is a time consuming and difficult task, and is better done once, as part of the representation language, in our case, OWL.

The second way in which the OHD facilitates access to information is by reducing the complexity of queries. Using the OHD's terms, information about intracoronal restorations can be represented as OWL 2 statements that are stored in a semantic database. Queries written in SPARQL can then extract the information for analysis. The construction of these queries takes the form of *subject-predicate-object* where the *subject* and *object* denote instances of the OHD's classes, and the *predicate* denotes relations between instances. For example, to find which surfaces were restored by some portion of dental restoration material, we can query the triple-store for instances of the class **dental restoration material** ?d that are related to instances of the class **surface enamel of tooth** ?s by the *is dental restoration of* relation with the following query:

select ?d ?s where {
  ?d *rdf:type* ohd:dental restoration material .
  ?s *rdf:type* ohd:surface enamel of tooth .
  ?d *ohd:is dental restoration of* ?s .}[4]

Querying information contained in an EDR system, however, is often not so straightforward. To issue a similar query against the EDR system we examined for our project would require a complex join across several tables. This has the drawback, again, of making the data less accessible, since many researchers will not have expertise in how table relationships work in a relational database. While we expect that most researchers will not have the expertise to develop SPARQL queries (themselves), the structure of the OHD more directly corresponds to the clinicians understanding of their work. This will make it easier for the researcher and SPARQL developer to communicate while developing queries to support research needs.

[4] While we write the terms of the query here using readable labels, the actual query uses the IRIs that identify the terms.

ACKNOWLEDGEMENTS

The writing of this paper was funded in part by grants R21-DE-19683 and R21-DE-21178 from the National Institute of Dental and Craniofacial Research (NIDCR), and by the University at Buffalo School of Dental Medicine. We would like to thank Mark Jensen and Lou Goldberg for their helpful comments.

REFERENCES

Brinkman, R. R., Courtot, M., Derom, D., Fostel, J. M., He, Y., Lord, P., . . . Zheng, J. (2010). Modeling biomedical experimental processes with OBI. *J Biomed Semantics, 1 Suppl 1*, S7. doi: 2041-1480-1-S1-S7 [pii] 10.1186/2041-1480-1-S1-S7

Grenon, P. (2003). Spatio-temporality in Basic Formal Ontology: SNAP and SPAN, Upper-Level Ontology, and Framework for Formalization PART I. *IFOMIS Reports, November*.

Grenon, P., Smith, B., Goldberg, L. (2004). Biodynamic Ontology: Applying BFO in the Biomedical Domain. In D. M. Pisanelli (Ed.), *Ontologies in Medicine* (Vol. 102, pp. 20-38). Amsterdam: IOS Press.

Mejino, Onard (2012). [personal communication].

Ontotext. OWLIM Retrieved from http://www.ontotext.com/owlim

Prud'Hommeaux, Eric, & Seaborne, Andrew. (2008). SPARQL query language for RDF *W3C Recommendation*: W3C.

Rosse, Cornelius, & Jr, Mejino JL. (2007). The Foundational Model of Anatomy Ontology. In A. Burger, D. Davidson & R. Baldock (Eds.), *Anatomy Ontologies for Bioinformatics: Principles and Practice* (pp. 59-117). London: Springer.

Ruttenberg, Alan, Duncan, William, Schleyer, Titus, Haendel, Melissa, & Tornai, Carlo. (2012). Ontologies in Oral Health and Disease Project page. Retrieved April 26, 2013, from http://code.google.com/p/ohd-ontology

Ruttenberg, Alan, Stoeckart, Chris, Peters, Bjoern, Courtot, Melanie, Rees, Jonathan, & Smith, Barry. (2013). Information Artifact Ontology Project Page. Retrieved April 26, 2013

Scheuermann, Richard H., Ceusters, Werner, & Smith, Barry. (2009). Toward an Ontological Treatment of Disease and Diagnosis *Proceedings of the 2009 AMIA Summit on Translational Bioinformatics, San Francisco, California, March 15-17, 2009* (pp. 116-120): American Medical Informatics Association.

Smith, B., Ashburner, M., Rosse, C., Bard, J., Bug, W., Ceusters, W., . . . Lewis, S. (2007). The OBO Foundry: coordinated evolution of ontologies to support biomedical data integration. *Nat Biotechnol, 25*(11), 1251-1255. doi: 10.1038/nbt1346

Smith, Barry, Ceusters, Werner, Klagges, Bert, Köhler, Jacob, Kumar, Anand, Lomax, Jane, . . . Rosse, Cornelius. (2005). Relations in biomedical ontologies. *Genome Biology, 6*(5), R46.

W3C OWL Working Group. (2012). OWL 2 Web Ontology Language Manchester Syntax (Second Edition) *W3C Recommendation*: W3C.