# A Conceptual Model for an Ontology-Based Dietary Recommendation Plan in Crohn's Disease

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***Abstract*—Crohn's Disease (CD) is a long-term inflammatory bowel disorder that affects the digestive system. It is influenced by geography, diet, genetics, and immune response. Patients often experience difficulties managing CD due to the complexity and heterogeneity of the condition. Despite increasing scientific efforts, knowledge within the domain remains scattered and fragmented across different concepts. The purpose of this study is to develop a conceptual model of CD using knowledge engineering to organize domain knowledge and clarify the main aspects and their relationships. The conceptual model is created following the Ontology Development 101 methodology to define the creation of classes, properties, and restrictions. The proposed model is designed to organize and integrate multiple aspects of the condition, such as symptoms, treatments, risk factors, and patient profiles, with a particular emphasis on dietary recommendations. The resulting model consists of eight primary classes and fifteen key relationships, clarifying the connections between patients, symptoms, treatments, and diagnosis. The CD conceptual model does not comprehensively address the genetic, environmental, cultural practices, or neurobiological factors related to CD. To address these limitations, future work should focus on integrating real-world clinical data and considering broader demographic contexts. This study examines nutritional treatments for CD, such as Exclusive Enteral Nutrition (EEN), the low-FODMAP diet, and the Crohn's Disease Exclusion Diet (CDED) that emphasize the role of diet in personalized healthcare. The CD conceptual model developed is the basis for building a comprehensive ontology-driven system that will help Crohn's patients with personalized dietary advice and future decision support systems that will improve their clinical care.**

***Keywords*—Conceptual model; ontology; dietary recommendations; Crohn's Disease; domain knowledge**

## I. Introduction

One form of chronic inflammatory bowel disease (IBD) that has an impact on people's lives is CD. IBD causes chronic inflammation in the gastrointestinal tract, and its primary forms include CD and ulcerative colitis (UC) [1]. Both conditions share common characteristics such as symptoms, risk factors, and therapy. The causes of IBD are multifactorial and include environmental changes, susceptibility genes, abnormal gut microbiota and a disordered immune response [1]. Common CD symptoms include abdominal pain, severe diarrhea, fatigue, weight loss, and malnutrition, which can significantly affect one's quality of life [2]. It substantially impacts various aspects of life, including daily functioning, social interactions, and psychological stress due to chronic pain [3]. The disease is incurable, causing physical, emotional, and financial burdens for patients due to ongoing medical expenses and potential loss of income [4]. CD can be effectively managed through medical treatment, nutritional support, and surgery when necessary [5] [2]. The burden of IBD has increased over recent decades, particularly in industrialized nations, with rising prevalence rates also being reported in newly urbanized regions [6]. According to recent estimates, by 2030, over 7 million people in Europe and the United States will suffer from IBD [4], with rising CD incidence rates in Asia and Latin America mirroring those in Western countries [7][8]. Currently, China and the USA have the highest number of cases [6]. In the Kingdom of Saudi Arabia, the frequency of IBD has significantly increased over the previous three decades [9]. Several studies have investigated the effect of nutritional management on patients with CD, as dietary factors can exacerbate or alleviate symptoms [10] [11]. Even though there are no specific guidelines for diets in this regard, as per a survey conducted in 2017, 71% of IBD patients believe that diet influences their condition [12]. Furthermore, 77% of patients reported avoiding certain foods to prevent disease relapse [13]. Finding reliable information on healthy lifestyle choices, such as maintaining a balanced diet, can be challenging. For example, a study revealed that half of IBD patients reported not receiving nutritional advice, while two-thirds expressed their interest in dietary guidance. Most preferred to receive this information from dieticians and gastroenterologists [11].

Research on CD encompasses various disciplines beyond nutrition, including immunology, genetics, microbiology, epidemiology, pharmacology, and psychosocial interventions. This multidisciplinary landscape reflects the complex nature of CD and highlights the challenges involved in integrating findings from various fields [14]. CD is characterized as a complex and heterogeneous disease in terms of its clinical features. This heterogeneity is reflected in disease location and behavior, differing treatment responses, disease progression, and a wide range of immunological and microbiome profiles [15]. The challenges of CD research are the fragmentation of knowledge across studies, resulting in scattered and unstructured information. To address this, approaches such as biomedical ontologies have become important. Biomedical ontologies have significantly enhanced knowledge management, data integration, reasoning, and decision support [16]. In the field of nutrition for health conditions, ontology-based approaches assist those struggling with chronic diseases, such as Diabetes [17], Obesity [18], and Chronic Kidney Disease [19].

Therefore, the solution requires an ontology-driven approach to analyze effects, symptoms, treatment, and nutrition needs, utilizing knowledge representation techniques to create a semantic map in biomedical data. Ontologies have various

terms across disciplines and purposes, gaining recognition in academic, industrial, engineering, and medical fields [20]. An ontology was initially defined by Gruber in 1993 as 'a formal, explicit specification of a shared conceptualization', and this is a commonly utilized approach for representing knowledge in computer science [21]. Ontologies have proven highly beneficial across various domains and play a crucial role in the semantic web for automated data exchange, gathering and connecting different information systems, and attracting domain experts' efforts [22].

This brings us to our current study, in which we aim to develop a conceptual model using an ontology-driven approach to CD. Specifically, we intend to address the following research questions: What core concepts and relationships are essential for developing a conceptual model and ontology that accurately represent Crohn's Disease, including its symptoms and dietary recommendations? To address this question, we use an ontological approach to introduce the CD conceptual model. This requires a comprehensive understanding of CD nature, effects, symptomatology, and a specific focus on nutritional ability to enhance the patient's overall health.

## II. Related Work

### A. A Review of the Conceptual Model in Crohn's Disease

Conceptual models of CD provide structured frameworks that explain the various aspects of the condition. These models are critical in integrating various types of knowledge, guiding treatment strategies, and improving patient management. This section highlights existing conceptual models in CD research and aims to address the gaps that have been identified. For example, Falling [23] proposed a conceptual model to explain how psychological and behavioral factors interact to influence pain in CD and IBDs. Using a cross-sectional survey of 174 adults and structural equation modeling, the study examined relationships between disease activity, insomnia, fatigue, pain severity, pain catastrophizing, and other patient factors such as depression and anxiety. It showed that modifiable factors directly affected pain interference, while additional patient factors had indirect effects. The authors emphasized the need for longitudinal and experimental research to validate the model, integrate clinical biomarkers, and inform targeted interventions to improve pain management in IBD. In addition, Williams-Hall et al. [24] developed a conceptual model based on patient and clinician insights as well as a literature review. This model explores the symptoms of CD and their impact on patients' quality of life. In addition, a CD diary was developed to document daily symptoms and the various effects of CD. The model identified the most burdensome symptoms, such as abdominal pain, bowel urgency, and fatigue, and linked them to emotional, social, and functional impacts. The results showed that these symptoms affect patients' daily activities, work or school performance, and physical functioning. The study emphasized that disease symptoms influence psychological and social well-being. In contrast, Kim et al. [25] developed a conceptual model that describes the impact of ulcerative colitis (UC) symptoms on patients' quality of life. This model shows that UC symptoms lead to both gastrointestinal and psychosocial effects, ultimately influencing the overall well-being of patients. Although both [24] and [25] addressed individual aspects such as biology, symptoms, psychological and behavioral factors, yet the role of diet as a therapeutic component remains unexplored in CD conceptual models.

These studies have established robust conceptual models that encompass various aspects of clinical research, especially concerning complex and heterogeneous diseases such as CD. Most existing models often focus on specific concepts such as symptoms, psychological or patient-reported outcomes, leaving gaps in a holistic understanding of CD. Therefore, this study presents a unified conceptual model that integrates nutritional aspects to enable the structured representation of CD domain knowledge. The proposed CD conceptual model aims to support future ontology-based systems that provide personalized dietary recommendations, with both scientific and practical applications.

### B. A Review of Ontological Models in Health and Nutrition

With the advent of the Semantic Web, ontologies have emerged as a model for knowledge representation across various scientific domains, notably in medicine [27], nutrition [22], industrial production [28], education [29], engineering [30], and numerous others. Several ontologies have been created to serve diverse domains related to nutrition. For example, Arwan et al. [31] designed and implemented an automation system for providing food recommendations and appropriate menus for type-2 diabetic patients using OWL and SWRL technologies. Food composition processing requires Ontology-based domain knowledge. The result of the system predicted 73% of the 30 data samples. Thus, the system decreased the reliance on nutrition experts. In addition, Clunis [32] develops an ontology for hypertensive individuals as a recommendation system. The ontology was constructed using the ontology development 101 methodology. The ontology includes recipes, food nutrients, interactions between nutrients, prescribed drugs, diseases, and general health. The validation involved proto-personas and created competency questions for testing the ontology. This study shows that an ontology-based system can enhance understanding of the complex relationships between diet and health outcomes, thereby improving decision-making for hypertension management. In contrast, Chi et al. [19] applied a knowledge-based system (KBS) for problem-solving modeling, utilizing Web Ontology Language (OWL) and Semantic Web Rule Language (SWRL). The system mimics dietitians' decision-making, saves time, and minimizes errors in dietary consultation for chronic kidney disease. OWL-based KBS recommends serving balanced amounts of food for nutrient intake. Similarly, Taçyıldız and Ertuğrul [18] develop an ontology-based system as a decision support system (DSS) for healthcare experts treating paediatric and adolescent overweight. It offers supportive dietary habits and recommends physical activities during the treatment process. The system uses medical data to provide health experts with personalized recommendations, utilizing an ontology-based inference engine module. The system's efficiency was evaluated and compared to human expert recommendations, showing promising results. In addition, Al-Nazer et al. [33] developed and integrated ontologies across various domains such as food, health, nutrition, and user profiles to enable personalized information retrieval for diet and health. This ontology will help patients

with diabetes and high blood pressure, considering dietary preferences and cultural or religious factors.

These previous studies have emphasized the importance of ontology-based approaches in managing chronic diseases, but these efforts remain limited in the context of CD. Their existing ontologies focused on nutrients and disease-specific dietary guidelines, without incorporating multiple disciplines such as psychology, comorbidities, or food allergies. Furthermore, each ontology operates as an isolated knowledge base, leading to the creation of knowledge from scratch rather than leveraging or linking to existing semantic resources. These gaps emphasize the need for a more structured approach, such as an ontology-based conceptual model that explains CD complex nature. Therefore, this study develops a conceptual model that serves as a critical initial step in formalizing and standardizing CD dietary knowledge for future system development and research endeavors. As illustrated in Table I, it provides a comprehensive overview of chronic disease ontologies, including diet recommendations.

TABLE I. AN OVERVIEW OF ONTOLOGY IN THE NUTRITION AND HEALTH DOMAINS

| Paper | Domain | Purpose | Linkage to External Ontologies & Their Data Source | Methodology | Evaluation |
|---|---|---|---|---|---|
| Arwan et al. [31] | Type 2 diabetes | To provide dietary recommendations for diabetes based on ontology and semantic matching | - No external ontology integration.<br>- Patients' profiles and nutrition databases | (1) Weighted Tree similarity method.<br>(2) An automatic approach.<br>(3) Semantic search method | Using SPARQL queries and a confusion matrix |
| J. Clunis [32] | Hypertensive | To develop an ontology to manage diet for patients with Hypertension | - Integrated external vocabularies from schema.org, FOAF, Dublin Core, and SKOS.<br>- USDA nutrient database and reliable web recipes. | Ontology 101 methodology | Competency questions for testing and creating Proto-personas |
| Y. L, Chi et al. [19] | Chronic Kidney Disease (CKD) | To create a knowledge base system (KBS) for patients to manage their condition through nutrition. | - No external ontology integration.<br>- Medical patient records and reliable open-source food data. | Ontological engineering (OWL-based Knowledge base Modeling) and semantic rules ( SWRL- based rules) | Domain expert and calculating the accuracy. |
| Ö. Taçyıldız and D. Ç. Ertuğrul, [18] | Obesity | To provide dietary and physical activity recommendations as treatment steps. Enables remote consultation and monitoring of patients. | - No external ontology integration.<br>- Pediatric patients' profile. | (1) Obesity Tracking Ontology,<br>(2) Semantic Web Rule Knowledge base, and<br>(3) Inference Engine Module. | Health experts calculate False Negative (FN) and other metrics. |
| A. Al-Nazer, et al. [33] | Diabetes & high blood pressure | To analyze user preferences and create a health and nutrition-focused profile. | - Integrated external ontologies such as Semantic Diet, AGROVOC, and Disease Ontology.<br>- Domain experts, surveys, and reliable health websites. | (1) Semantic web and ontology engineering technologies<br>(2) Personalization techniques and semantic processing techniques | Domain expert and Performance measures. |

## III. METHODOLOGY

This study presents a comprehensive ontology and conceptual model for the domain of CD. Recognizing the inherent relationship between conceptual modelling and ontology construction, for the conceptual model, we adopt a methodology guided by the Ontology Development 101 methodology [34]. This methodology was chosen for its ability to balance knowledge representations, the use of restrictions, and the extendibility of the ontology for future definitions [35]. It provides a clear, step-by-step guide that covers all stages of the conceptual model, including class hierarchies and instances. This iterative method ensures alignment among concepts, domain objects, and relationships, making it relevant and applicable in its domain. Such alignment leads to the development of a well-structured conceptual model that incorporates domain knowledge and expert insights for effective knowledge sharing and decision support. By employing this methodology, the conceptual model is developed based on a set of iterative steps, as shown in Fig. 1.

### A. Capture Domain Knowledge and Conceptualization

*1) Determine the domain, scope, and purpose:* This step establishes a solid foundation for developing a conceptual model that accurately captures and represents the intended knowledge area. It serves as a foundation for developing an ontology for CD. Through exploring domain heterogeneity, defining the model's boundaries, and clarifying its overall objectives. During this stage, it is essential to address several questions to ensure the model meets its intended objectives, such as "The conceptual model is being created; why?" "Who are the intended users?" and "What domain does the conceptual model cover?" Table II presents the scope of the domain for the proposed CD ontology [26].

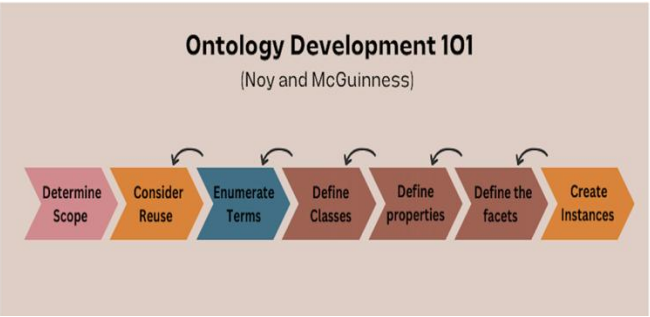


Fig. 1. The CD conceptual model development methodology.

TABLE II. THE PROPOSED DOMAIN AND SCOPE OF THE CD CONCEPTUAL MODEL

| | |
|---|---|
| **Domain** | This work focuses on the medical and dietary domain related to CD. |
| **Date** | 2024 - 2025 |
| **Location** | King Abdulaziz University, Jeddah, KSA |
| **Party (Organization)** | Student in Information Systems department at the Faculty of Computing and Information Technology |
| **License Model** | Academic Research |
| **Purpose** | The purpose of CD conceptual model is to provide a reliable resource for understanding CD, focusing on symptomatology, treatments, and dietary recommendations. This model aims to support patients with CD and their caregivers looking for evidence-based dietary recommendations, enhancing their self-management of the condition. It covers the domain of CD with a specific focus on nutrition. It includes symptom and treatment information to create personalized dietary plans for patients. |
| **Scope** | The conceptual model's scope reflects the domain knowledge found in the semantic structure of the model. The CD conceptual model aims to represent the complex nature of CD. It includes various aspects, such as the causes and risk factors of the disease, symptoms, diagnostic criteria, stages of the disease, treatment strategies with an emphasis on dietary therapy, and related conditions. |
| **Ontology Type** | Domain Knowledge |
| **Engineering Methodology** | Ontology Development 101 Methodology |
| **Source of Knowledge** | • Medical & Nutritional Portal such as, National Institutes of Health NIH [36], Food and Agriculture Organization (FAO) [37], Food ontology [38], Disease ontology [39] and NCBO BioPortal [40].<br>• Knowledge from Domain experts (interviews).<br>• Review various Scientific Research & Journals. |

*2) Consider reusing existing conceptual model:* It is a critical step to conduct a comprehensive examination of existing ontologies, vocabularies, taxonomies, and components relevant to the domain. Reviewing these existing models enables the identification of reusable components that can be extended or integrated into the CD conceptual model. It is important to document and blueprint these resources. The model contains biomedical and nutrition conceptual models related to CD or IBD, which were found in a separate format.

*3) Enumerate important terms:* During the model development stage, it is crucial to define all the terminologies that will be used. This step should be done iteratively to identify and include all relevant terms and concepts. To accomplish this, gathering information from various sources, such as existing taxonomies, databases, books, and domain experts' knowledge, is recommended. By collecting a comprehensive list of essential terms related to CD, including Related Condition that contain of inflammatory bowel diseases (IBD) and gastrointestinal disorders including Ulcerative Colitis (UC), and Irritable Bowel Syndrome (IBS), Symptoms such as abdominal pain and diarrhea, that Caused by a combination of genetics (e.g. problems with the immune system, environmental factors, and an imbalance of gut bacteria), Diagnostic methods, Disease Stages, Risk factors of potential comorbidities and complications (e.g., Colon Cancer and Depression), and Treatments (such as medication and dietary therapy). This list of terms serves as a foundation for the next steps, where the key terms are chosen as the main classes, and the other terms become subclasses or properties, which are often refined through iteration. The goal is to gather a comprehensive list of terms without concern for any overlap between the concepts they denote, the relationships among the terms, or any specific properties associated with these concepts.

*4) Define the classes and their hierarchy:* This involves organizing important terms, defining their properties, and analyzing the information gathered to group them into classes. Several ways to create a class hierarchy, such as top-down, bottom-up, or a combination of both [41]. Organizing these terms into a hierarchical structure can create subclasses under a particular class. For example, under the class "Treatment", we could have subclasses like "Medication" and "dietary therapy", as shown in Fig. 2. Each class should represent a concept essential for understanding CD. Classes are fundamental components that illustrate key concepts related to CD. Defining these classes clarifies the conceptual model and establishes a structured foundation for building the ontology, as shown in Table III.

*5) Define the properties of classes:* It is a key step in the conceptualization phase, as each class must have attributes that outline its structure and relationships. The object property names typically start with "has" (e.g., hasSymptoms). In addition, Object properties usually have corresponding inverse properties, such as their inverses with "isSymptomOf". Additionally, data properties may have cardinality constraints that specify how many relationships an individual can have for a given property, as illustrated in Table IV.

*6) Define the facets of the slots:* In this step, each property is linked with a class based on its cardinality, range, and domain. This approach ensures that the conceptual model is structured and semantically accurate. It enhances the CD conceptual model scope, coherence, and structure for transitioning into a formal ontology representation, as illustrated in Table IV.

TABLE III. PRIMARY CLASSES OF THE CONCEPTUAL MODEL OF CD

| Class | Description |
|---|---|
| **Related condition** | Refers to medical issues that often occur alongside IBD due to related symptoms. Examples include UC and IBS [42] |
| **Causes** | It is caused by a combination of multiple factors that may contribute to CD, including environmental changes, susceptibility genes, abnormal gut microbiota, and a disordered immune response [1]. |
| **Diagnosis [26]** | This class refers to diagnostic methods that are used to detect, monitor, and confirm CD [42] |
| **Disease Stages** | It refers to the various stages of CD, ranging from severe active to prevalence balance. Additionally, it aids in tracking disease progression and guiding treatment decisions [43]. |
| **Symptoms** | This term refers to common medical symptoms of CD, including abdominal pain, diarrhea, and fatigue, which contribute to the disease's severity [42] |
| **Risks** | A list of potential comorbidities and complications associated with CD that affect patients [44]. |
| **Treatment** | Strategies for management and intervention that include pharmacological therapies, dietary modifications, and surgical interventions [45]. |
| **Patient** | Characteristics of patients with CD, such as age, BMI, and allergy. |

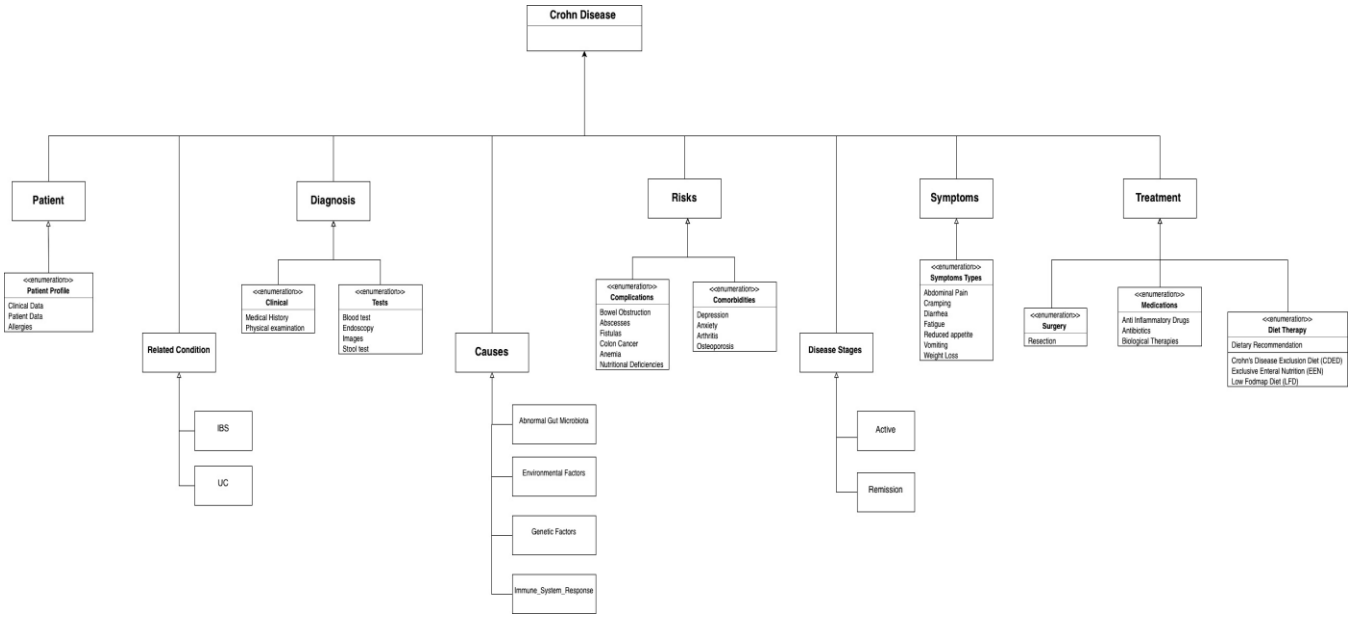


Fig. 2. Top-level CD conceptual model.

TABLE IV. CD CONCEPTUAL MODEL PROPERTIES

| Property Name | Domain | Range | Cardinality | Inverse property |
|---|---|---|---|---|
| hasSimilarSymptoms | Crohn Disease | Related Condition | Many-to-many: a Crohn Disease can be associated with multiple Related Conditions and each Related Condition may be linked to more than one disease. | isRelatedToCrohn |
| hasCauses | Crohn Disease | Causes | Many-to-many: a Crohn Disease can occur from many Causes factors and each Cause may be linked to multiple diseases. | isCauseOf |
| hasDiagnosisMethods | Crohn Disease | Diagnosis | Many-to-many: a Crohn Disease can be diagnosed through multiple methods and each Diagnostic method may be applied to several gastrointestinal disorders. | isDiagnosedBy |
| hasDiseaseStage | Diagnosis | Disease Stage | One-to-one: as each Diagnosis will correspond to a specific Stage of the disease | isStageOf |
| hasSymptoms | Patient | Symptoms | Many-to-many: a Patient may have more than one Symptom and many Patients may experience each Symptom. | - |
| hasSymptoms | Diagnosis | Symptoms | Many-to-many: a Diagnosis may have more than one Symptom and each Symptom can be associated with different Diagnoses. | isSymptomOf |
| isDiagnosedBy | Patient | Diagnosis | One-to-many: a Patient can have more than one Diagnosis, while each Diagnosis belongs to a single Patient. | - |
| hasRisks | Crohn Disease | Risks | Many-to-many: a Crohn Disease may have more than one Risk factor. | isRiskfor |
| isRiskfor | Risks | Patient | Many-to-many: a Patient can have multiple Risk factors and each risk factor may be associated with several patients. | hasRisks |
| isManagedBy | Symptoms | Treatment | Many-to-many: a Symptom may have more than one Treatment | manages |

*7) Create the instances:* In the final step of the CD model, individual instances of classes are created to populate the conceptual model with concrete examples. This process consists of three main steps: selecting a class, constructing an instance for that class, and assigning values using object or data properties. For example, the classes Dietary Therapy and Dietary Recommendation fall under the class Treatment. These instances serve as a transition from the conceptual model to a comprehensive formal ontology and knowledge base.

## IV. CD CONCEPTUAL MODEL

This study presents a conceptual model that integrates core aspects of CD, such as symptoms, treatments, risk factors, patient profiles and focus on dietary intervention through defined relationships. Therefore, the conceptual model is valuable for assessing the quality of ontologies, whether they are constructed from scratch or adapted from existing ones. It improves the understanding of the domain for both creators and users by representing essential system properties in a clear and structured manner. This approach promotes clarity, completeness, and enhanced usability [46]. In this phase, we focused on providing a high-level overview of the ontology domain by presenting a conceptual model encompassing its content. Fig. 3 illustrates a UML class diagram that shows the classes and relationships. Each class represents a key aspect of the domain, covering categories like patient, related conditions, symptoms, causes, risks, disease stages, treatments, and diagnostic criteria.

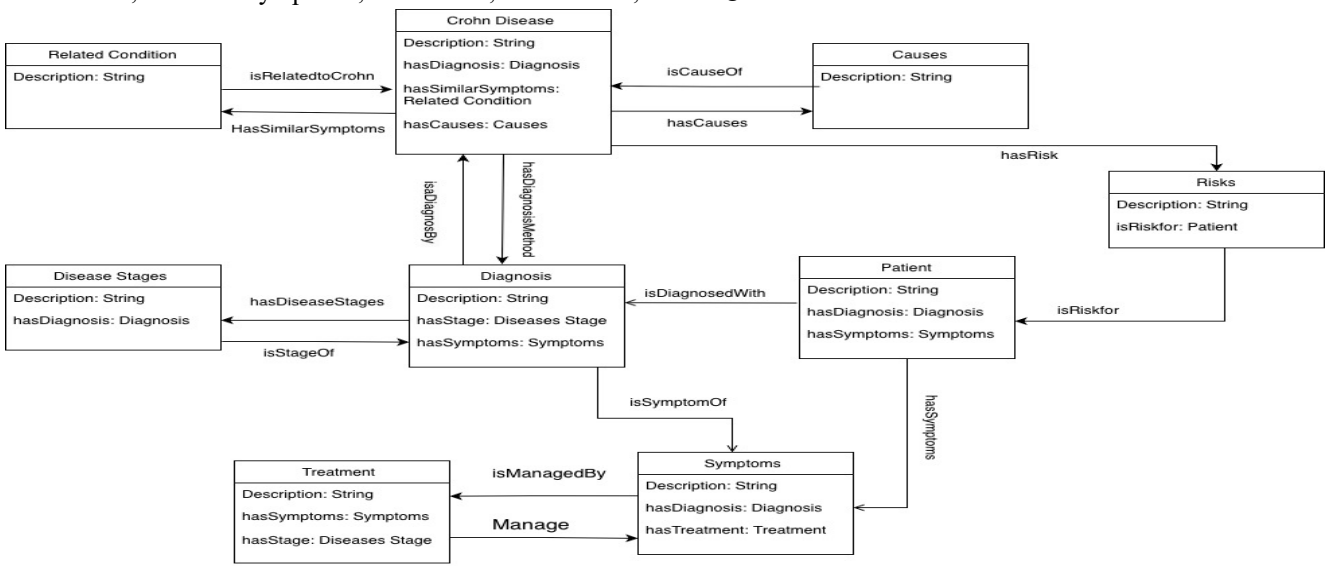


Fig. 3. The CD conceptual model.

The relationship between these classes is supported by clinical repositories, scientific research, and domain experts. The conceptual model highlights the meaningful connections between these essential concepts. By synthesizing findings from various sources, the model illustrates how these core concepts interact, forming a foundational blueprint for the ontology of CD. In the following paragraph, we address an overall conceptualization of CD. The CD conceptual model outlines the primary top-level classes that are most relevant to the study's focus, demonstrating how each class contributes to the development and interpretation of the proposed conceptual model. The defined classes are structured under the superclass CD, which integrates four entities: Patient, Diagnosis, Symptoms, and Treatment, especially dietary recommendations that reflect the primary aspect of the domain. The patient class is the primary entity that represents individuals undergoing medical observation and treatment. Two key relationships define the Patient class, which are 'hasSymptom' and 'isDiagnosedWith'. The 'hasSymptom' relationship links a patient to one or more instances of the Symptom class. The patients often present with several symptoms, such as abdominal pain, diarrhea, and fatigue. These symptoms serve as primary indicators for further diagnostic investigation. Besides, the 'isDiagnosedWith' relationship represents the result of the diagnosis methods. This method involves a combination of clinical evaluation and objective testing (e.g., endoscopy, imaging, and blood tests). This diagnosis method involves the recognition of the condition and ensures that the ontology reflects evidence-based processes [47]. These relationships illustrate the patient's journey from symptoms to diagnosis confirmation. This facilitates the patient's status through customized treatment plans, such as dietary interventions. In addition, the Diagnosis class is linked to the Disease Stages class through the relationship "hasDiseaseStages", and its inverse relationship "isStageOf". Therefore, involves assigning a stage based on the severity of disease activity, such as active and remission. This connection is crucial for determining appropriate treatment, monitoring disease progression, and customizing dietary plans to manage CD. Furthermore, the symptom class is connected to the treatment class through the relationship 'isManagedBy', which reflects the role of various interventions, especially dietary recommendations. Meanwhile, the inverse relationship 'manages', indicates that specific symptoms can be managed through appropriate therapeutic strategies such as surgery, medications, or diet therapy. Symptoms and treatments play a critical part in determining disease management strategies. This will play a role in forming appropriate and personalized

therapeutic options for patients through different possibilities of diet recommendations such as EEN, the low-FODMAP diet, and CDED.

Our conceptual model was developed to build an ontology that defines key aspects, relationships and constraints related to CD which intended to capture expert knowledge. Thus, ensure clarity and consistency before formal implementation in OWL or other ontology languages. The proposed conceptual model aims to develop a comprehensive domain ontology that reflects the understanding of CD. In addition, highlights the dietary recommendations as therapeutic knowledge.

## V. Result and Discussion of the CD Conceptual Model

The CD conceptual model was developed through a structured knowledge-engineering methodology synthesizing evidence from various sources, such as scientific research and domain experts. This section addresses the research question by identifying the essential concepts and relationships needed to represent CD, thereby capturing its symptoms, patient profile, and dietary recommendations into a comprehensive unified conceptual model. The resulting model integrates the core concepts of CD into a unified framework, including Patient, Related Conditions, Symptoms, Causes, Diagnosis, Disease Stages, Risks, and Treatment. These eight top-level classes are interconnected through fifteen well-defined relationships, providing a coherent and comprehensive representation of the domain. The CD conceptual model was modified after incorporating expert suggestions to increase completeness and clinical applicability. In response, Quality of Life (QoL), was introduced as a distinct class linked to the Patient class through the object property 'hasQualityOfLife' and the inverse 'isQualityOfLifeOf' to reflect its centrality in CD outcomes. While, QoL linked to symptom through the property 'impactsQualityOfLife' and the inverse property 'isImpactedBySymptom', indicating that multiple symptoms may influence a patient's QoL [48]. This refinement is significant because previous models discussed in the related work section rarely conceptualized QoL as a formal class, defining their ability to represent the psychosocial and behavioral dimensions of IBD. By linking QoL to symptoms, the proposed model offers profound insights into the way dietary interventions can affect overall well-being, representing a significant advancement in the CD field. Fig. 4 illustrated the updated CD conceptual model, highlighting that QoL is associated with both patient and symptom classes. This refinement enhances the clinical relevance of the model and strengthens its suitability for future ontology development and decision-support applications.

Within the field of CD, several studies have attempted to conceptualize various aspects of domain knowledge. However, these efforts remain limited, focusing on isolated aspects such as pain interference [23], quality-of-life impacts in ulcerative colitis [24], or daily symptom reporting [25]. Despite these studies having developed robust conceptual models that address various aspects of CD, this study distinguishes itself by emphasizing the distinctive contributions of this study. Therefore, this study aims to fill that gap by proposing a CD conceptual model that unifies these aspects into a cohesive framework integrating dietary therapy with symptom, disease progression, and psychosocial concepts. Furthermore, it serves as the foundational structure for the CD ontology.

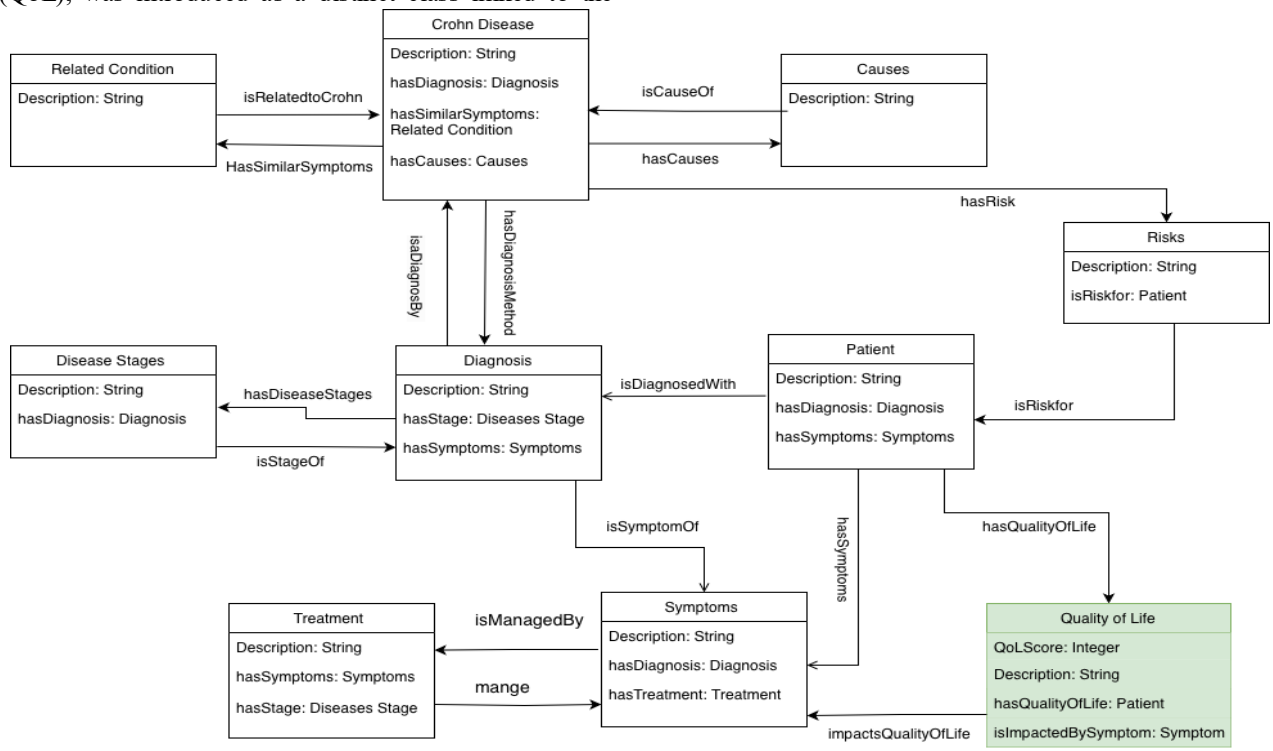


Fig. 4. The refined CD conceptual model including QoL.

## VI. Conclusion

CD creates a multifaceted burden that impacts both medical and psychosocial aspects of a person's life. The presented conceptual model describes the main components of this burden, aiming to guide and improve future therapeutic and dietary strategies. To conclude, this study introduced a comprehensive conceptual model that represents the complex and heterogeneous nature of CD by using the Ontology Development 101 methodology. The result of the CD conceptual model suggests an integrated view of the disease by establishing relationships among eight top-level classes, which are Causes, Risks, Diagnosis, Disease Stages, Symptoms, Treatment, Related Conditions, and Patient. The model defines fifteen semantic relationships that illustrate the connections among its primary elements. By integrating these components, the model provides a comprehensive representation of these relationships between medical and nutritional domains. Moreover, it provides a unified model that enables caregivers, patients, and researchers to explore evidence-based dietary plans and insights related to CD. The model's contribution lies in its ability to support personalized dietary planning, which enhances both research and clinical practice.

Although the conceptual model encompasses a broad range of CD Knowledge, it does not incorporate detailed classes of genetic, microbiome, or allergic factors that influence individual variability. Another limitation relates to the cultural region, and behavioral factors affecting dietary adherence remain limited. In order to overcome these limitations, future work should incorporate patient-reported outcomes, nutritional assessments, and integrate real-world patient data to validate the model's correctness and improve clinical applicability. This includes incorporating longitudinal QoL and daily symptom diaries that will improve the model's ability to track disease progression effectively. Additionally, linking with external ontologies and conceptual model components relevant to the domain will improve interoperability.

Ultimately, this study will progress from conceptual modeling to develop a Crohn's Disease Ontology called OntCrohn's to support intelligent decision-making systems and personalized dietary recommendations. This study contributes to the precise and adaptive management of CD by alleviating patient symptoms and improving quality of life.

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## Ethics and Data

In this study, no patient identifiers were used. All data used were obtained from open-access literature or publicly available medical and dietary repositories. If future research versions of the ontology integrate patient or clinical data, appropriate ethical procedures will be followed. This includes obtaining informed consent, implementing strict anonymization protocols, and ensuring complete alignment with Institutional Review Board (IRB) requirements.

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