# Building an Expert System to Guide Diagnosis and Management of Rhinossinusitis

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## 1 Background

Rhinosinusitis is a common condition with implications on the quality of life of patients and on healthcare costs, particularly within primary care settings. In the United States, it affects approximately one in seven adults annually, accounting for 6 to 15% of ambulatory care visits and over three million consultations across all ages each year. Acute rhinosinusitis (RS) is most often caused by viral infections, such as rhinovirus, coronavirus and influenza, and is associated with upper respiratory tract infections, with nearly 90% of viral upper respiratory tract infections involving concurrent acute RS. Nevertheless, only 0.5 to 2% of cases progress to acute bacterial RS, which is typically caused by *Streptococcus pneumoniae, Haemophilus influenzae, Staphylococcus aureus, or Moraxella catarrhalis.*[1–4]

RS is categorized based on the duration of symptoms: acute (up to four weeks), subacute (more than four but fewer than twelve weeks), and chronic (twelve weeks or more). There are multiple clinical guidelines, such as the ones from the Infectious Diseases Society of America (IDSA) and the American Academy of Otolaryngology Head and Neck Surgery (AAOHNS), that provide criteria for diagnosing acute rhinosinusitis. Criteria usually focuses on symptoms, such as purulent nasal discharge, facial pain, nasal obstruction, and systemic signs of infection. However, there are variations across different guidelines and differing between viral and bacterial cases remains diagnostically challenging, especially in time-limited primary care or urgent care settings.[5–7]

Despite the favorable natural history of acute RS, where approximately 85% of cases resolve within 7 to 15 days without antibiotic therapy, antibiotics are prescribed in 84 to 91% of cases diagnosed in emergency, urgency and outpatient settings. This overprescription is attributed to diagnostic uncertainty, patient expectations for antibiotics, and inconsistent adherence to clinical guidelines. Literature studies show that multiple randomized placebo-controlled trials failed to demonstrate a significant benefit of antibiotic therapy for acute RS. Systematic reviews reveal only a slight increase in clinical improvement with antibiotics compared to placebo (success rates of 77 to 88% vs. 73 to 85%, respectively). The number needed to treat (NNT) for one patient to benefit ranges from 7 to 18, while the number needed to harm (NNH) due to side effects ranges from 8 to 12. Adverse effects such as nausea, diarrhea, and abdominal pain occur in approximately 27% of patients receiving antibiotics, compared to 15% of those on placebo. Furthermore, the widespread and often unnecessary use of antibiotics contributes to the global issue of antimicrobial resistance. Thus, overprescription of antibiotics not only increases the risk of adverse effects but also the risk of antibiotic resistance.[2,8–16]

Because of important diagnostic and management variability and consequences of inappropriate antibiotic use, tools that guide clinical reasoning promoting standardized decision-making can be valuable assets. AI tools can be developed to address these challenges and, if developed with thorough methodological approach and rigorous study design, can potentially improve diagnostic accuracy and adherence to evidence-based guidelines, assisting clinicians in time-limited situations or in uncertain cases. While reviewing the literature, two AI tools in rhinosinusitis management were found, RHINA CDSS and a Decision Support System with U-Net Segmentation. RHINA, from the Charles University in Prague, provides direct recommendations for rhinosinusitis diagnosis and management. The decision Support System with U-Net Segmentation, from the Kharkiv National Medical University in Ukraine, uses computer imaging methods to guide differential diagnosis of chronic odontogenic rhinosinusitis.[17–21]

During this project, a detailed expert system will be developed. The proposed expert system for this project will use clinical guidelines from IDSA and AAO-HNS with data from a clinical case provided by the clinical provider, such as symptoms, presentation duration, and clinical findings and conclusions. The system will assist in distinguishing rhinosinusitis from upper respiratory viral infections, differentiating viral from bacterial rhinosinusitis, and classifying cases as acute, subacute, or chronic. Moreover, it will provide evidence-based management recommendations,

considering potential complications and the need for hospitalization or referrals. The aim is for the developed tool to diminish diagnostic variability and antibiotic overprescription, providing standardized assistance, that potentially helps to improve patient outcomes.

## 2 Materials and Methods

For this final project, an expert system was developed using CLIPS.py[22] in a Jupyter Notebook[23]. The report was written using LaTeX[24] via OverLeaf[25]. References were created using Mendeley[26] and added to the report through a references.bib file. The expert system aims to assist clinical providers in diagnosing and managing RS. While creating the expert system, guidelines were used as a foundation, mainly the IDSA and AAO-HNS recommendations. Templates were defined for the several different steps of the process. Inference rules were created using forward chaining logic, with propositional logic conditional statement (if then) and boolean operations (and, not, or). The inference engine faces and processes input data through a knowledge base, providing the user with diagnostic and therapeutic recommendations. The output is generated in steps, not all at once. Based on the input of the user, the system will match a specific rule and process accordingly, which can include printing a recommendation or asking another question. If the first answer is "yes" the following question will differ compared to if the first answer is "no", for example. Flow diagrams of the steps of the expert system were created using draw.io[27] and can be seen in Figures 1 and Figure 2.

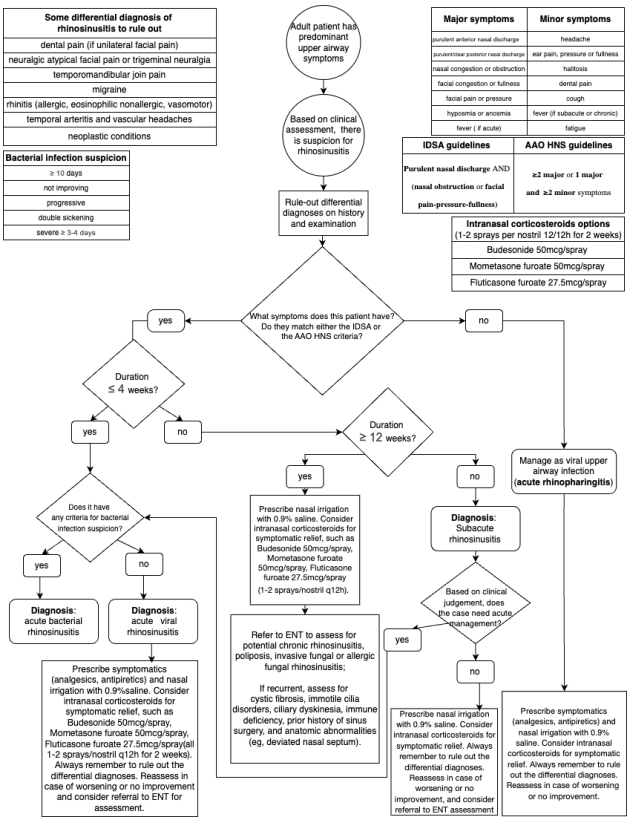


**Figure 1:** Expert System Part 1 - Rhinosinusitis Suspicion and Diagnosis - Flow Diagram

Figure 1 illustrates the first part of the expert system, which performs the following steps: (i) checks if the expert system is the appropriate decision track for the case under consideration; (ii) checks if the case meets the criteria for rhinosinusitis; (iii) classifies the case based on duration; and (iv) provides recommendations on diagnosis and management based on the responses to the prompts.

Figure 2 illustrates the second part of the expert system, which will be focused on the cases considered to be acute

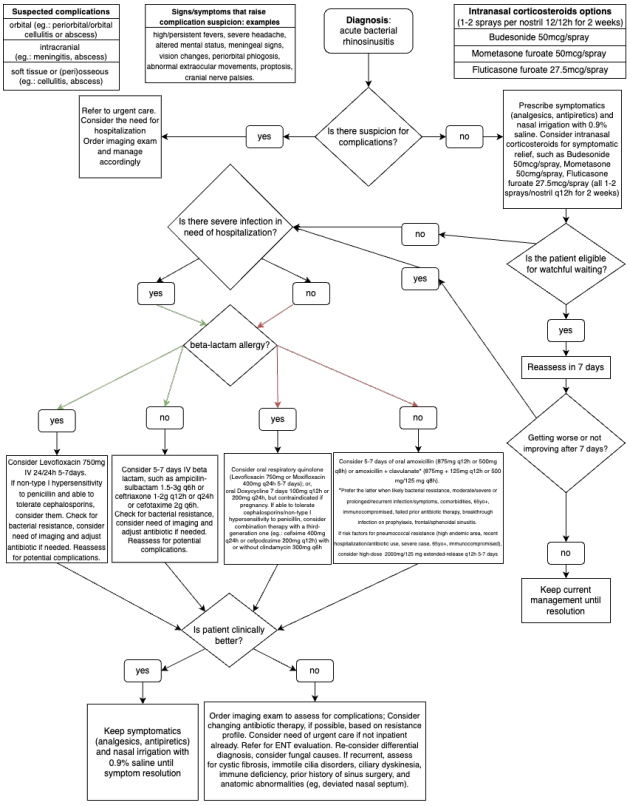


**Figure 2:** Expert System Part 2 - Acute Bacterial Rhinosinusitis Management - Flow Diagram

bacterial RS or subacute bacterial RS in need of acute management. This part will perform the following steps: (i) checks for complications or signs and symptoms suggestive of complications; (ii) evaluates eligibility for watchful-waiting; (iii) checks if cases that undergone watchful-waiting got worse or failed to improve after one week; (iv) checks if cases are severe and in need of hospitalization; (v) checks for beta-lactam allergies; (vi) evaluates clinical improvement after initial management; and (vii) provides management recommendations based on the combination of responses for that case.

## 2.1 Design

This project integrates several concepts learned during this semester as part of the 5200 Foundations of Artificial Intelligence course. The expert system was developed using propositional logical operations (eg.: and, or, not) and conditional statements (eg.: if then), to define logical rules, and first-order predicate logic (eg.: (acute_rhinosinusitis (criteria_met yes))) to represent facts, allowing the system to make inferences based on the clinical provider's input (system user). The system follows forward chaining, a rule base reasoning method that starts with available facts and uses inference rules to gather more input data as needed. By following these rules, the expert system will suggest diagnoses and treatment recommendations, based on data gathered from the user. The knowledge base consists of facts (from user input and predefined data) and rules, matched according to instructions written using literature references and clinical guideline criteria. The system is implemented using CLIPS and python (via clips.py), adhering to the course's concepts of rule definition, knowledge base creation, and inference engine implementation. In the beginning of the notebook, an overview of the expert system was added with flow diagrams exemplifying the functionality of the tool.

The development process began by importing necessary modules, including clips, clips_util, and creating a clips

environment within the notebook to allow the use of clips.py and logging is implemented to ensure that strings are captured in the output. The expert system is designed using a series of inference rules to diagnose and manage rhinosinusitis cases based on patient data. The system gathers information through predefined templates, processes the input using rules, and outputs diagnosis and management recommendations.

### 2.1.1 Templates

First, a series of templates was defined to allow the expert system to gather input data:

1. The initial decision track templates include patient information such as age, sex, predominant symptoms (particularly if they are related to the upper airway), and whether the clinician suspects rhinosinusitis. These templates will be used later to check whether the decision-making process is adequate for the current clinical case, as part of a rule defined later in the system.
2. The rhinosinusitis criteria templates were written to be used to determine whether the case meets the diagnostic criteria for rhinosinusitis. The criteria are based on symptoms presentation, including general, major, and minor symptoms, and the templates will be used to question whether these symptoms are present or not.
    - General symptom: purulent nasal discharge
    - Major symptoms: purulent anterior nasal discharge, purulent or clear posterior nasal discharge, nasal congestion or obstruction, facial congestion or fullness, facial pain or pressure, hyposmia or anosmia and fever
    - Minor symptoms: headache, ear pain, pressure, fullness, halitosis, dental pain, cough and fatigue
3. The symptoms duration template will be used to assess the duration of symptoms, which is critical for classifying the condition as acute, chronic, or subacute.
4. The bacterial infection suspicion templates were written to check the number of days the patient has been symptomatic, the presence of improvement, worsening or severe symptoms, and whether there is clinical suspicion of a bacterial infection, which will be used later to evaluate whether the case shows characteristics suggestive of a bacterial infection.
5. The acute management in subacute cases template was written to be used later to assess if subacute rhinosinusitis requires acute management based on clinical evaluation.
6. The bacterial complications template was written to be used later to check for potential bacterial complications (eg.: orbital, intracranial, soft tissue or osseous) and potential signs and symptoms that raise suspicion for complications to better define the following step.
7. The treatment recommendations templates were written to be used later to guide treatment decisions, including whether watchful-waiting is appropriate, if the condition worsens or does not improve after 7 days, if hospitalization is necessary due to severe infection, if there is a beta-lactam allergy, and whether the patient shows clinical improvement.
8. The criteria matching templates were written to be used at the end of the rules to assess whether the criteria are met for key decision points. These include the initial decision track, rhinosinusitis, acute rhinosinusitis, bacterial suspicion, subacute rhinosinusitis needing acute treatment, chronic rhinosinusitis, bacterial complications, watchful-waiting, worsening or no improvement, severe infection requiring hospitalization, beta-lactam allergy, and clinical improvement.

Then, the knowledgeable is initialized with all criteria status set to ”unknown” initially. The criteria status is updated as the rules are processed.

### 2.1.2 Rules

Inference rules were created to ensure the system is working as designed.

1. The first set of rules gathers initial patient information and uses the initial decision track templates' responses to ensure that the decision track is appropriate (initial decision track rules), according to the logic of the rule. For the decision track to proceed, all of the following criteria must be met: the patient is 18 years or older, predominance of upper airway symptoms and clinical suspicion of rhinosinusitis.

   If any of these criteria are not met, the system will stop gathering information and show the following message: *"This decision track is for adult cases with suspicion for rhinosinusitis, not pediatric or cases without predominance of upper airway symptoms or suspicion for rhinosinusitis. If pediatric patient, please refer to pediatric guidelines as these might differ from the adult one. If predominant symptoms are not upper airway then other diagnosis need to be considered or if there is no rhinosinusitis suspicion, this is not the correct decision track for this case."*

   If the criteria are met, the system proceeds with further questions for rhinosinusitis diagnosis and a message will be printed *"Apart from using this decision track, also consider differential diagnosis, ruling them out, such as dental pain (if unilateral facial pain), neuralgic atypical facial pain or trigeminal neuralgia, temporomandibular joint pain, migraine, rhinitis (allergic, eosinophilic nonallergic), vasomotor headaches, neoplastic conditions."*. The commands to print the string messages are in the reporting rules (initial decision track check reporting rules), which contain the reporting rules (with string messages), based on the answers for the initial_decision_track above.

2. The rhinosinusitis criteria rules are defined for the system to check if the case meets the criteria for rhinosinusitis by asking about the presence of symptoms, major symptoms and minor symptoms, using the templates defined previously. The criteria used will be based on the AAO-HNS and IDSA clinical guidelines.

   - AAO-HNS: purulent nasal discharge accompanied by: nasal obstruction; or by facial pain or pressure; or by facial congestion or fullness.
   - IDSA: at least two major symptoms or the combination of one major symptom and at least two minor symptoms.

   If rhinosinusitis criteria are not met, the system will stop execution and print: *"This patient does not match the criteria for rhinosinusitis. Manage as a viral upper airway infection/acute rhinopharingitis. Prescribe symptomatics(analgesics, antipyretics) and nasal irrigation with 0.9% saline. Consider intranasal corticosteroids for symptomatic relief. Always remember to rule out the differential diagnoses. Reassess in case of worsening or no improvement."*

   If rhinosinusitis criteria are met, the system will start rhinosinusitis duration assessment and print string: *"This patient matches the criteria for rhinosinusitis."*

3. Following the rhinosinusitis duration rule, the system will gather input on symptom duration to determine if the case is acute or non-acute. According to IDSA and AAO HNS guidelines, rhinosinusitis is acute if symptoms last four weeks or less.

   If the symptoms are not acute, the system will proceed to chronic rhinosinusitis management.

   If the symptoms are acute, the system proceeds to assess bacterial suspicion.

4. Following acute rhinosinusitis bacterial suspicion rule, this section will gather input on characteristics that raise suspicion for bacterial infection in acute cases, from bacterial infection suspicions templates defined previously, to define if bacterial suspicion is present. If symptoms persist for ten or more days without improvement or show progressive worsening, or if there is double sickening, or if severe symptoms are present for three or more days, or if the clinician considers the case suspicious for bacterial infection, the case will be classified as suspicious for bacterial infection.

If bacterial suspicion is present, the system will print *"Diagnosis: acute bacterial rhinosinusitis"* and proceed to bacterial complications assessment.

If bacterial suspicion is not present, the system will print *"Diagnosis acute viral rhinosinusitis. Prescribe symptomatics(analgesics, antipyretics) and nasal irrigation with 0.9% saline. Consider intranasal corticosteroids for symptomatic relief, such as Budesonide 50mcg/spray, Mometasone furoate 50mcg/spray, Fluticasone furoate 27.5mcg/spray(all 1-2 sprays/nostril q12h for 2 weeks). Always remember to rule out the differential diagnoses. Reassess in case of worsening or no improvement."*

5. The non-acute rhinosinusitis duration rule will gather input on the duration of the symptoms, using the a symptom duration template, to check whether the case is subacute or chronic.

   If duration of symptoms is 12 weeks or more, it will print message: *"Prescribe nasal irrigation with 0.9% saline. Consider intranasal corticosteroids for symptomatic relief, such as Budesonide 50mcg/spray, Mometasone furoate 50mcg/spray, Fluticasone furoate 27.5mcg/spray (1-2 sprays/nostril q12h). Refer to ENT to assess for potential chronic rhinosinusitis, poliposis, invasive fungal or allergic fungal rhinosinusitis. If recurrent, assess for cystic fibrosis, immotile cilia disorders, ciliary dyskinesia, immune deficiency, prior history of sinus surgery, and anatomic abnormalities (eg, deviated nasal septum)"*.

   If duration of symptoms is 12 weeks or lower, it will print message: *"Diagnosis: Subacute Rhinosinusitis"* and procedd to assess for need of acute management.

6. The bacterial rhinosinusitis complications rule will gather input on whether there is suspicion for complications, using the bacterial complications templates previously defined, and will be important to define management recommendations.

   If bacterial complications are suspected, the system will print: *"Consider the need for hospitalization. Order imaging exam and manage accordingly"* and assess for bacterial complications.

   If bacterial complications are suspected, the system proceed to check for possibility of watchful-waiting and print message *"Prescribe symptomatics (analgesics, antipyretics) and nasal irrigation with 0.9% saline. Consider intranasal corticosteroids for symptomatic relief, such as Budesonide 50mcg/spray, Mometasone furoate 50mcg/spray, Fluticasone furoate 27.5mcg/spray (1-2 sprays/nostril q12h)."*

7. The watchful-waiting eligibility rule will gather input on whether there is eligibility for watchful-waiting, using the corresponding template.

   If there is eligibility, system will print message *"Reassess in 7 days"* and continue evaluation, which will consider that the patient is back for follow-up after watchful waiting. Clinicians could come back to the decision track to use this part after the week.

   If clinical assessment considers the patient to be not eligible, the system will continue evaluation to define best therapeutic management.

   If a week of watchful-waiting was done and patient is back for follow-up, a rule will be used to define if there is a need to consider further treatment or if current management is working.

8. A rule will gather input on whether, after a week of watchful-waiting and symptomatic management, there has been any worsening or no improvement, using the pre-define template.

   If worsening or no improvement after a week of watchful waiting, the system will start asserting rules to define further treatment needs.

   However, if there is no worsening and there is improvement after a week, the system will print message: *"Keep current management until resolution"*.

9. If a case of acute or subacute bacterial rhinosinusitis cannot undergo watchful-waiting (rule 1), or if it did undergo watchful-waiting but does not improve or worsens (rule 2), the assessment for therapeutic management will begin. The severe infection requiring hospitalization rule will classify the case as inpatient or outpatient based on whether there is a severe infection requiring hospitalization, using a predefined template.

If there is suspicion for severe infection with need for hospitalization, the system will proceed to checking for presence of beta-lactam allergy.

If there is no suspicion for severe infection with no need for hospitalization, the system will proceed to checking for presence of beta-lactam allergy.

10. Rules were created to check for beta-lactam antibiotic allergy for non-hospitalized patients (rule 1) and for hospitalized patients (rule 2), gathering input on whether outpatient and inpatient cases have beta-lactam allergy, using pre-defined template.

    If outpatient has beta-lactam allergy, the system will print message *"Consider oral respiratory quinolone (Levofloxacin 750mg or Moxifloxacin 400mg q24h 5-7 days); or, oral Doxycycline 7 days 100mg q12h or 200mg q24h, but contraindicated if pregnancy. If able to tolerate cephalosporins/non-type I hypersensitivity to penicillin, consider combination therapy with a third-generation one (eg.: cefixime 400mg q24h or cefpodozime 200mg q12h) with or without clindamycin 300mg q6h."* and check for clinical improvement after initial management.

    If outpatient does not have a beta-lactam allergy, the system will print message *"Consider 5-7 days of oral amoxicillin (875mg q12h or 500mg q8h) or amoxicillin + clavulanate* (875mg + 125mg q12h or 500 mg/125 mg q8h). *Prefer amoxicillin + clavulanate when bacterial resistance is likely, smoker/smoker in the family, recent antibiotic use, close contact with treated individuals/health care providers/health care environment/children in daycare, moderate/severe or prolonged/recurrent infection/symptoms, comorbidities, 65yo+, immunocompromised, failed prior antibiotic therapy, breakthrough infection on prophylaxis, frontal/sphenoidal sinusitis. If risk factors for pneumococcal resistance (high endemic area, recent hospitalization/antibiotic use, severe case, 65yo+, immunocompromised), consider high-dose amoxicillin + clavulanate 2000mg/125 mg extended-release q12h 5-7 days."* and check for clinical improvement after initial management

    If inpatient has beta-lactam allergy, the system will print message *"Consider Levofloxacin 750mg IV 24/24h 5-7days. If non-type I hypersensitivity to penicillin and able to tolerate cephalosporins, consider them. Check for bacterial resistance, consider need of imaging and adjust antibiotic if needed. Reassess for potential complications."* and check for clinical improvement after initial management.

    If inpatient does not have a beta-lactam allergy, the system will print message *"Consider 5-7 days IV beta lactam, such as ampicilin-sulbactam 1.5-3g q6h or ceftriaxone 1-2g q12h or q24h or cefotaxime 2g q6h. Check for bacterial resistance, consider need of imaging and adjust antibiotic if needed. Reassess for potential complications."* and check for clinical improvement after initial management

11. The clinical improvement rules will check for improvement after initial therapeutic management. Rule 1 will be applied in cases that did not undergo watchful-waiting and rule 2 will be applied in cases that did undergo watchful-waiting but did not improve or got worse, requiring further therapeutic management. This rules will gather input on whether the patient got better after first management, using adequate template.

    If clinical improvement, the system will print message *"Keep symptomatics(analgesics, antipyretics) and nasal irrigation with 0.9% saline until symptom resolution"*.

    If no clinical improvement, the system will print message *"Order imaging exam to assess for complications; Consider changing antibiotic therapy, if possible, based on resistance profile; Consider need of urgent care if not inpatient already. Refer for ENT evaluation. Re-consider differential diagnosis, consider fungal causes. If recurrent, assess for cystic fibrosis, immotile cilia disorders, ciliary dyskinesia, immune deficiency, prior history of sinus surgery, and anatomic abnormalities (eg, deviated nasal septum)."*

After running all the templates and rules, using the functions env.reset(), env.run(), the system will gather input from the user and provide outputs as the answers are being provided and rules are matched. Then, using the print_facts(env) function, the system will print the list of all facts and how many were generated.

### 2.2 Demonstration

All the work developed for this project, including the Jupyter notebook, is available in the GitHub repository,5200 Final Project Antonia. The expert system is working and four output examples are shown in Figure 3: (i) case of non-complicated inpatient acute bacterial RS, without beta-lactam allergy and no clinical improvement after first treatment; (ii) case of non-complicated outpatient subacute bacterial RS with beta-lactam allergy, that worsened or failed to improve after a week of watchful-waiting, requiring further management with antibiotics and achieving clinical improvement after that; (iii) case of non-complicated outpatient acute bacterial RS with clinical improvement after a week of watchful-waiting; and (iv) case of complicated acute bacterial RS.

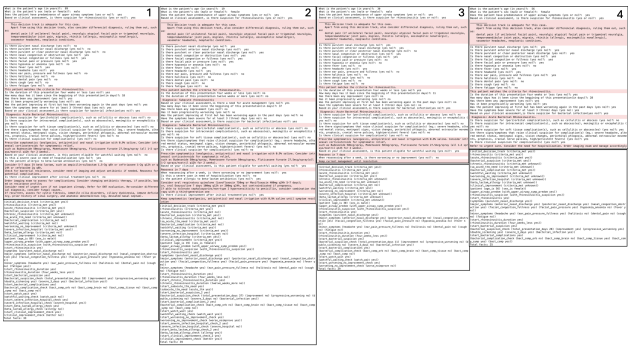

**Figure 3:** Expert System Output Examples

To view and run the expert system locally, users need to install Anaconda/Jupyter Notebooks, Python and CLIPS on their system. Once these are installed, users can download the files from the Expert_system_project_ANTONIA folder in the GitHub repository or clone the repository into a folder on their local computer and then download the files. The files should be added to a new folder created within Jupyter notebook, optionally through Anaconda. From there, the final_project_demo_Antonia.ipynb file can be opened and executed to see the expert system functioning. The tool is currently working as intended, as demonstrated in Figure 3. Testing was conducted to ensure all possible outputs are correctly generated, addressing and fixing challenges that appeared during the testing. Examples of all possible outputs from the tool are provided in the outputs_examples.pptx file in the Github repository.

## 3 Discussion and conclusions

This expert system has potential to be a useful tool in clinical practice to guide clinical reasoning in diagnosing and treating RS cases, following current guidelines. By offering standardized management recommendations, this tool can help reduce unnecessary antibiotic prescriptions and ensure more accurate initial assessments. This lowers healthcare costs by reducing the number of repeat visits and helping to reduce the burden of antibiotic resistance. Moreover, providing accessible, evidence-based guidance can improve adherence to guidelines, especially among general practitioners in primary and urgent care settings where there is often limited time to evaluate the patients.

During this expert system's development process, a key challenge involved resolving conflicting logic rules that occasionally overshadowed one another. Careful code review, fine-tuning, debugging and testing resolved the issues, resulting in a version that provides reliable outputs for all decision pathways. It is important to stress that this expert system remains a functional prototype that requires further refinement, especially in the user interface, to ensure a smooth integration into clinical practice.

Future plans for the development of this tool include expanding the system's functionality to include patient comorbidities and pregnancy status to provide more personalized recommendations. Also, expanding this tool's usability to include other diagnoses, potentially other upper airway conditions, can broaden its utility. Improving its visual interface, integrating it with existing platforms and adding features, such as session-saving options that allow users to pause and resume interactions without losing progress, can improve the user experience and potentially increase the adherence to the tool. Furthermore, updating the knowledge base regularly is essential to ensure alignment with the latest guidelines. Overall, refining the system's functionality and usability can help build clinician trust, increasing the

likelihood of adoption.[16,18,20]

This expert system has the potential to support clinical providers in diagnosing and managing RS cases while following current guidelines. It is important to always highlight this tool's role as a guidance for clinical reasoning rather than a replacement for it. By fostering better decision-making and reducing unnecessary prescriptions, this expert system has the potential to improve healthcare outcomes and tackle antibiotic resistance. Continued development and broader application could amplify its impact, addressing a range of global health challenges.

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