Application of Bayesian Methodology to a Clinical Case

(Simple Demonstration of the SMDB)

Statement of Illness and Background Information on Patient

Mr. Sam Jones is a 37-year-old married white male who presents with multiple upper respiratory complaints. He is new to this clinic secondary to his having recently changed employers, and hence insurance carriers. He currently works as a janitor at a local school.

Chief Complaint: 'I have this cough, and my throat is very sore.'

Complains of night sweats, waking the patient two to three times a night for the last three nights. Complains of cough, non-productive at first, now with mucopurulent discharge, occasionally blood tinged, times five weeks. Category

Construct Initial Probability Distribution

$$P(\Psi \mid \mathbf{S}\,\mathbf{I}) = \begin{cases} \text{Conditional Probability for Catagory of Illnesses} = \Psi\text{(Vector)} \\ \text{Conditioned on Symptoms Vector } \mathbf{S} \text{ and Any Other Prior Information } \mathbf{I} \\ \text{Concerning the Patient and His Medical History} \end{cases}$$

Any illness Ψ_1, Ψ_2, Ψ_3, … Ψ and Ψ_p is likely. The Ψ_i's are a range of illnesses that correspond to the stated symptoms given in **S**, and Ψ_p is the final outcome—a specific illness with an associated probability of being true—of the analysis. The result of this construct would typically look as that displayed in figure 1.

Medical Examination

Physical Examination:

1. Vital signs

a. Blood pressure: 124/70

b. Pulse: 85

c. Respiration: 20

d. Temperature: 101 degrees Fahrenheit

2. General description: the patient is a 37 year old married white male who looks his stated age; he is pleasant, appears well nourished, and seems in an overall good state of health.

3. Skin: warm and dry; turgor adequate; color normal. There is no icterus, purpura, rash, or unusual pigmentation noted. Hair normal in appearance, distribution, texture.

4. Lymph nodes: no cervical, supraclavicular, axillary, epitrochlear, or inguinal adenopathy.

5. HEENT (Head, Ears, Eyes, Nose, Throat):

    a. Head: normocephalic and atraumatic; no lesions noted.

    b. Eyes: cornea without lesions, conjunctiva clear, sclera white. Pupils are equal, 3mm in diameter, round, reactive to light and accomodation. Extraocular movements within normal limits without nystagmus or strabismus. Fundii are benign. Disks well delineated. There are no hemorrhages or exudates. Visual acuity is 20/20 bilaterally, and visual fields are within normal limits to confrontation.

    c. Ears: normal in appearance. Auditory canals clean and without lesions. Tympanic membranes intact. Hearing adequate.

    d. Nose: septum within normal limits and without deviation. Nasal mucosa pink and without abnormal discharge. No nasal polyps or other lesions. Frontal and maxillary sinuses nontender.

e. Mouth and throat: lips without cyanosis or pallor. Buccal mucosa normal in appearance. Teeth in good condition. Tongue without lesions or tremor, protrudes midline. Pharyngeal mucosa is erythematous and without other lesions, exudates, or evidence if inflammation. Gag reflex intact.

6. Neck: neck is supple, full range of motion. No evidence of tracheal deviation, jugular venous distension, or lymphadenopathy. Carotid pulses are 2+, equal bilaterally, and without bruits. Carotid upstroke is within normal limits. Thyroid normal in size, palpation reveals no nodules or masses.

7. Back: spinal curvature is normal; no scoliosis, kyphosis, or tenderness. Full range of motion present.

8. Chest: thorax is symmetric. Full expansion bilaterally. AP diameter is within normal limits.

9. Lungs: fremitus is equal bilaterally. Lung fields resonant throughout. Breath sounds and voice sounds normal. There are no rales or ronchi, but some end-expiratory wheezes throughout, more prominent in the bases bilaterally.

10. Heart: palpation reveals no heaves or thrills. The PMI (point of maximum impulse) is medial to the midclavicular line, fourth intercostal space. Auscultation reveals S1, S2, of normal intensity. There are no S3, S4, rubs, clicks, or other abnormal heart sounds. Heart rate is 70 BPM and rhythm is regular.

11. Breasts: breasts are symmetric and of normal contour. Skin is of normal color and appearance; there is no edema, ulceration or erythema. Nipples are of normal size and shape;

there is no nipple retraction, ulceration or discharge. Palpation does not reveal any tenderness or masses.

12. Abdomen: normal size and contour. There are no capillary dilatations, skin lesions, or surgical scars. Auscultation reveals normative bowel sounds and no abdominal bruits. Palpation reveals no abdominal tenderness, guarding, or masses. Liver edge is felt approximately 1 inch below the right coastal margin; it is firm, sharp, and smooth. The liver percuses to approximately 8 to 10 cm. total span. The spleen is not palpable.

13. Rectal exam: no external anal lesions. Sphincter tone normal. No internal or external hemorrhoids. Rectal mucosa appears normal, with no nodules or masses present. Stool is brown and negative for occult blood.

14. Genitalia: inspection reveals normal distribution of pubic hair. No lesions or discharges. No external lesions. Testes are descended, nontender, of normal size, without nodules or masses.

15. Inguinal area: no lymphadenopathy noted. Femoral pulses are 2+ and equal bilaterally. Auscultation reveals no femoral bruits.

16. Extremities: there is no clubbing, cyanosis, or edema. Brachial, radial, popliteal, dorsalis pedis, and posterior tabialis pulses are 2+ and equal bilaterally. Musculoskeletal exam reveals no joint deformities and full range of motion. There is no bone, joint, or muscle tenderness noted.

17. Neurologic: patient is alert and oriented to time, person, and place. Cranial nerves II to XII are within normal limits. Speech, memory, and expression are within normal limits. Muscle strength is 5/5 in both upper and lower extremities. There is no muscle atrophy or

involuntary movement noted. Testing of cerebella function reveals normal gait, negative Romberg test, and good coordination in finger-to-nose, heel-to-shin, and alternate motion testing. Sensory is intact to light touch, pain, and vibratory stimuli. There are no focal motor/sensory deficits. Deep tendon reflexes are 2+ and equal bilaterally.

Chosen Tests Include:

1. Throat culture and sensitivity (including strep): rapid strep test (poor but widely used) is negative. 24 and 48 hour cultures are positive for streptococcus sensitive to a wide range of older antibiotics. Mycoplasma culture will take a week or more to return, somewhat more difficult to do reliably, and is not chosen.
2. Chest X-ray, PA and LAT (back to front and side views). The pictures show very light patchy bilateral infiltrates, without consolidation.
3. A PPD (TB test) is chosen, and planted. A mycobacteria culture is not chosen (possibly a mistake) at this time.

The Diagoses to be Ruled Out Include:

1. Strep infection
2. Pneumonia
3. Residual mycoplasma infection
4. Mycobacteria infection (tuberculosis)

Construct Data Set (Vector) D and New Symptoms Vector S'

The data set is made up of the information contained in the seventeen (17) steps of the Physical Examination, that obtained from the three (3) Laboratory Tests and from the four (4) Diagnoses Ruled Out:

D = {(D_1, D_2, … D_{17}—Physical Exam), (D_{18}, D_{19}, D_{20}—Lab Tests), (D_{21}, D_{22}, D_{23}, D_{24}—Ruled

Out)}

In addition, the physician and/or the patient may have identified one or more symptoms not initially reported. The symptoms vector must be updated:

$$\mathbf{S'} = \mathbf{S} + \text{Additional Symptoms Observed.}$$

Construct a New Probability Distribution for the Illness Ψ Using D, S' and Bayes' Theorem

$$P(\Psi \mid \mathbf{D}\ \mathbf{S'}\ \mathbf{I}) = \left\{\begin{array}{l}\text{Conditional Probability for Reduced Range of Illnesses} - \Psi\text{(Vector)} \\ \text{Conditioned on New Data } \mathbf{D}, \text{ Updated Symptoms Vector } \mathbf{S'} \\ \text{and Any Other Prior Information } \mathbf{I} \\ \text{Concerning the Patient and His Medical History}\end{array}\right.$$

$$P(\Psi \mid \mathbf{D}\ \mathbf{S'}\ \mathbf{I}) = [P(\mathbf{D} \mid \Psi\ \mathbf{S'}\ \mathbf{I})\ P(\Psi \mid \mathbf{S'}\ \mathbf{I})] \,/\, P(\mathbf{D} \mid \mathbf{S'}\ \mathbf{I}),$$

where

$P(\Psi \mid \mathbf{S'}\ \mathbf{I})$ = Prior probability density that Ψ is true based on previous symptoms and tests on patients other than the one currently under examination,

$P(\mathbf{D} \mid \Psi\ \mathbf{S'}\ \mathbf{I})$ = Likelihood of Ψ based purely on current evidence. Confidence based on current symptoms and tests,

and

$P(\mathbf{D} \mid \mathbf{S'}\ \mathbf{I})$ = Probability Density for **D**.

The new distribution is much narrower in the range of illnesses it spans and peaks about the most probable illness, Ψ_p as illustrated in figure 2. At this point, the physician, based on other past case experiences with similar symptoms and/or professional instinct, has an option of selecting the most probable illness, Ψ_p, to treat or one of a small number of other illnesses within a nominal 0.99 probability "threshold" as indicated in figure 2.

A Presumptive Diagnoses of possible strep infection, possible mycoplasma infection is made. Less likely is TB. The patient will be treated as an outpatient. The SMDB is accessed for presenting symptoms and signs. It is found that in the last 30 days there have been 19 cases of students or staff of that school diagnosed with mycoplasma infection. This makes that diagnoses now overwhelmingly likely.

All have responded to a course of erythromycin (not universally true for this infection). Inhaled bronchodilators, and inhales steroids.

The Patient Treatment Plan

The SMDB is designed to be an effective tool in helping to select a course of treatment for the patient. Two in puts are needed: the most probable illness, Ψ_p, and a final determined set (vector) of symptoms, $\mathbf{S}_f$, which may be identical to **S'**. When this information is put into the SMDB it returns a probability distribution of treatment, **T**,

$$P(\mathbf{T} \mid \mathbf{S}_f \Psi_p \mathbf{I}) = \left\{ \begin{array}{l} \text{Conditional Probability of Treatment(s), } \mathbf{T} \\ \text{Conditioned on Symptoms Vector } \mathbf{S}_f \text{ and Any Other Prior Information } \mathbf{I} \\ \text{Concerning the Patient, His Medical History Including Medication} \\ \text{Information} \end{array} \right.$$

As illustrated in figure 3, the return may be a suggested board range of treatments, T_1, T_2, … .

Tailoring the Treatment Plan

\The treatment plan may be tailored to conform to additional information. First a new data set (vector), **d**, is constructed. This data set will contain information such as simplicity of treatment, cost and insurance coverage, patient's preferences, additional information concerning the patient his medical history and medication reactions if not included in the prior information, **I**, etc., etc.

From this information the SMDB will employ the Bayesian Methodology and construct the most probable distribution of treatments.

$$P(\mathbf{T} \mid \mathbf{d}\, \mathbf{S}_f\, \Psi_p\, \mathbf{I}) = [P(\mathbf{d} \mid \mathbf{T}\, \mathbf{S}_f\, \Psi_p\, \mathbf{I})\, P(\mathbf{T} \mid \mathbf{S}_f\, \Psi_p\, \mathbf{I})] \,/\, P(\mathbf{d} \mid \mathbf{S}_f\, \mathbf{I}),$$

where

$P(\mathbf{T} \mid \mathbf{S}_f\, \Psi_p\, \mathbf{I})$ = Prior probability density that **T** is true based on the determined illness, Ψ_f, the symptoms, $\mathbf{S}_f$, associated with Ψ_f and other prior information, **I**.

$P(\mathbf{d} \mid \mathbf{T}\, \mathbf{S}_f\, \mathbf{I})$ = Likelihood of **T** based on no directly knowledge of Ψ_p.

and

$P(\mathbf{d} \mid \mathbf{S}_f\, \mathbf{I})$ = Probability Density for **d**.

The new distribution is much narrower in the range of treatments it spans and peaks about the most probable illness, T_p as illustrated in figure 4. At this point, the physician, based on other past case experiences with similar situations and/or professional instinct, has an option of selecting the most probable treatment, T_p, or one of several other treatments that nominally fall within 0.99 probability "threshold" as indicated in figure 4.

A course of erythromycin (both because of the above information, and to nail the last doubt about a possible strep infection, and helping to prophylax against the latter).

- A two week course of an inhaled bronchodilator.
- A two week course of an inhaled steriod.
- Return in two days to have PPD read.
- Return in two weeks for follow up and to schedule an initial intake to the service.

The PPD is negative in two days: no action taken. Patient reports good symptomatic relief with the inhaled medication.

Two-week follow up shows a satisfactory resolution of symptoms: productive cough is absent times 8 days; patient is afebrile. Lungs are now clear. No follow up chest X-ray is needed. Oropharynx is now clear with no erythema.

Update/Upgrade SMDB

This patient's medical event now become part of the SMDB, and hence part of the knowledge informing subsequent decisions for other uses of the SMDB.

Summary

While this case does not involve life and death issues, as do cancer diagnosis and treatment, it is sufficient to illustrate the utility of the SMDB. Unless the treating team was directly involved in the other cases from the school, or had prescient knowledge about them, this confirmatory data would not be available. While in this case the resulting benefits included higher confidences in diagnosis and treatment, increased treatment efficacy, lower resource consumption all around, (all worthwhile goals), in most cases in the management of serious chronic illness, these advantages will accrue a thousand fold more. In addition, the issues of quality of life, morbidity and mortality, resource availability, access to treatment, are all vitally important areas, which will see significant benefits from the SMDB function.

Moreover, a portion of the SMDB subsumes the typical medical record and administrative record functions. This alone will not only enhance those roles, but also reduce costs involved with them.

Figure Captions

Fig. 1. P(Ψ | **S I**) vs. Ψ Probability distribution for a category of illnesses versus the range of illnesses in that category conditioned on only symptoms and any prior information.

Fig. 2 P(**D** | Ψ **S' I**) vs. Ψ Most probable distribution of illnesses conditioned on physical examination, laboratory tests, diagoses ruled out, patient's medical history and any prior information.

Fig. 3 P(**T** | $\mathbf{S}_f$ Ψ_p **I**) vs. **T** Probability distribution for various treatments conditioned only on the determined set of symptoms, the most probable illness (see Fig. 2.) and any other prior information.

Fig. 4 P(**T** | **d** $\mathbf{S}_f$ Ψ_p **I**) vs. **T** Most probable distribution of treatment conditioned on additional information, **d**, such as cost and insurance coverage, patient's preferences, additional information concerning the patient his medical history and medication reactions if not included in the prior information, **I**.

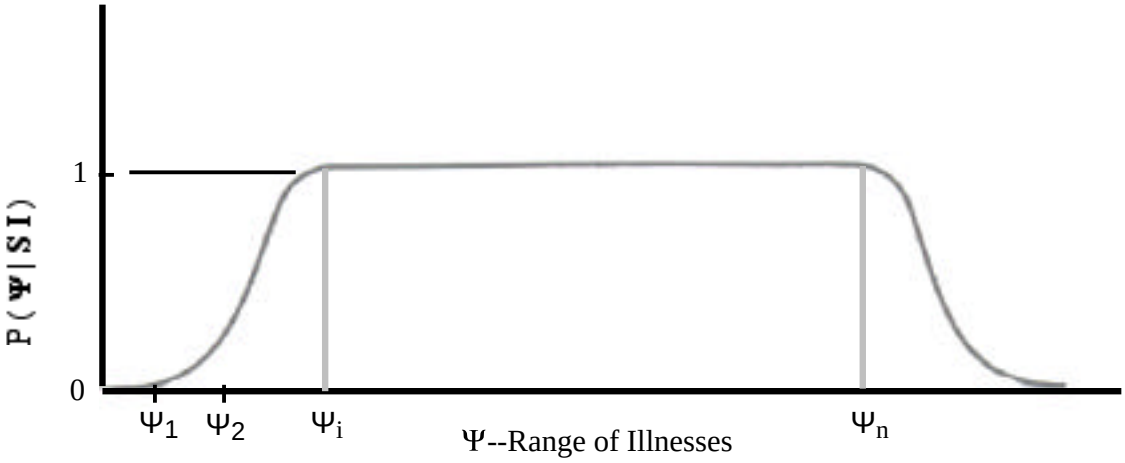
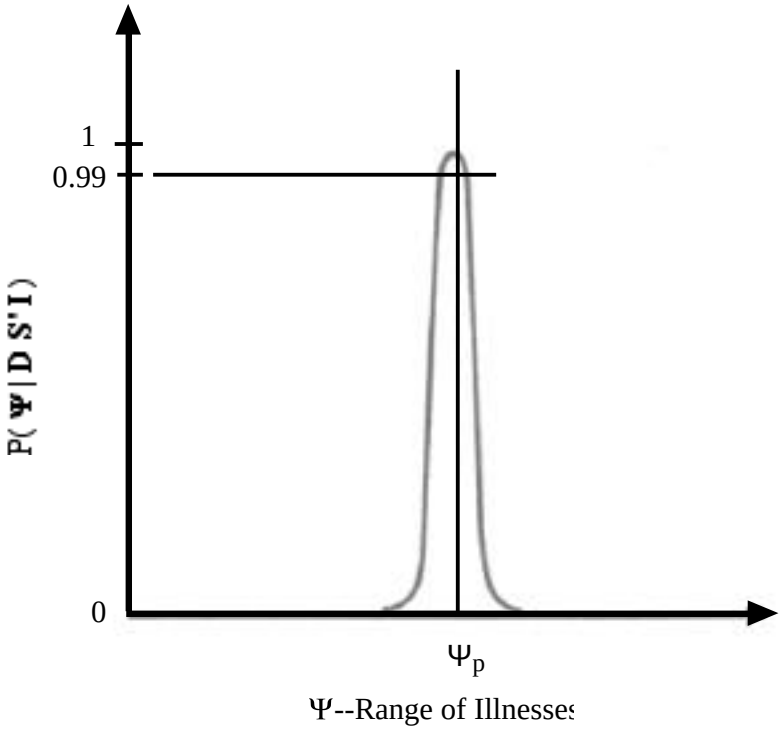

1
0
P (Ψ | S I)
Ψ1
Ψ2
Ψi
Ψn
Ψ--Range of Illnesses

Fig. 1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Ψ--Range of Illnesses

Fig. 2

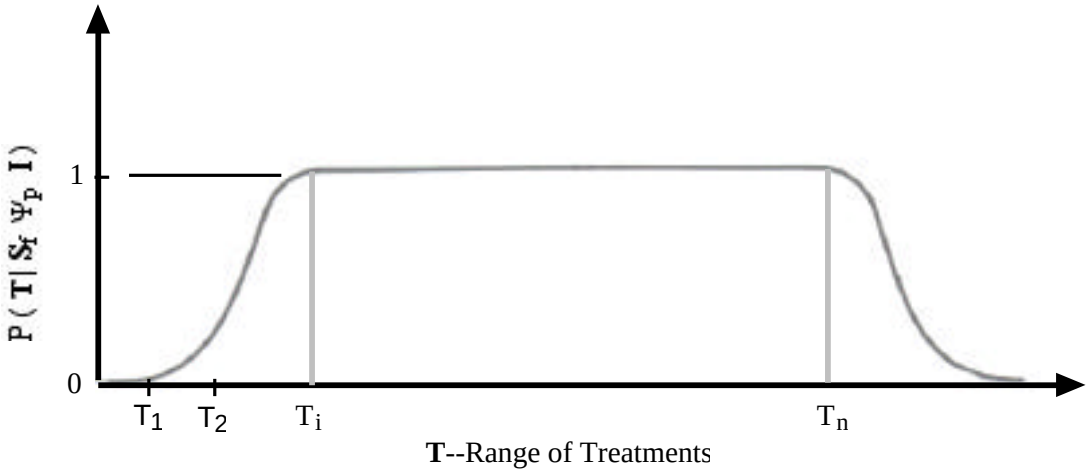
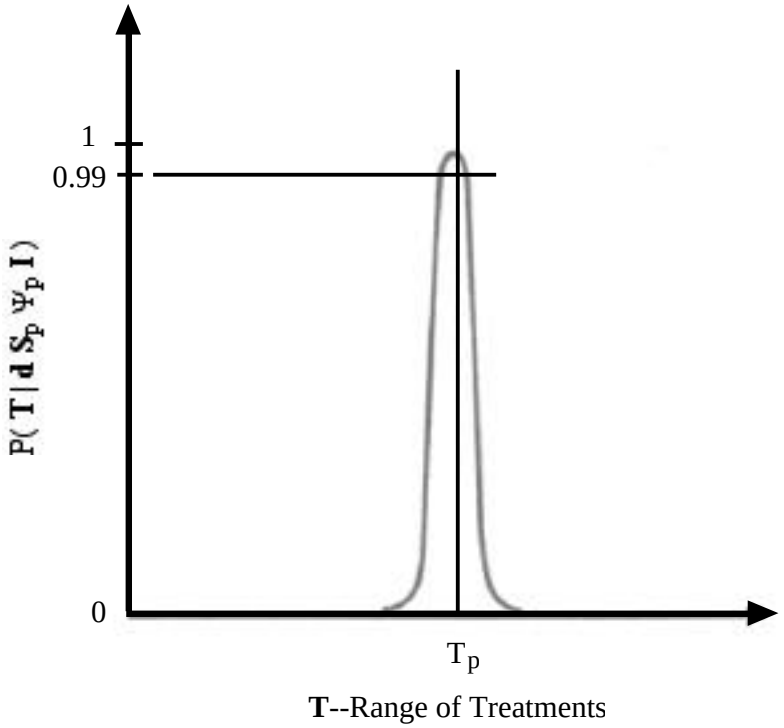

P (T | Sr Ψp I)
1
0
T1
T2
Ti
Tn
T--Range of Treatments

Fig. 3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P(T | d Sp Ψp I)
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Tp
T--Range of Treatments

Fig. 4