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A M E R I C A N C O L L E G E O F



C H E S T

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Alice in Intensiveland

Being an Essay on Nonsense and Common Sense in the ICU, After the Manner of Lewis Carroll

Robert H. Bartlett, MD, FCCP*

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Being a medical student, Alice perceived the hospital as a place of wonder. Being a medical student, Alice thought of herself (if she ever thought of herself) as intelligent, practical, educable, compassionate, and potentially competent to care for the sick. All she needed to accomplish this task was knowledge, and armed with 2 years worth of basic facts, she now sought to acquire that knowledge in this Wonderful Place. She had, metaphorically of course, consumed and deleted, grown and shrunk, read the lines and between the lines, and passed through her own reflection to get here. Now she was ready to begin the grand adventure. That was when she saw Dr. Rabbit.

Dr. Rabbit was hurrying down the hallway, walking so briskly and looking so nervously at his watch that he nearly knocked her over. White shoes, white pants, white tunic covered by a white coat stained by some unidentified biologic fluid. Dr. Rabbit was an intern, but he looked like a White Knight of the Wonderful Place to Alice.

"Excuse me sir, can you help me?"

"No. But yes. Yes, but no."

"Excuse me sir?"

"Yes, I could help you if I knew what your problem was, which I don't. But even if I did I'm in such a terrible hurry that, no, I can't help you if I could. I'm late, you see, for rounds and I must hurry. So if I could help which I might not be able to in any case, I can't, so goodbye."

"My problem is," said Alice in her practical fashion, "that I am supposed to report to the intensive care unit. Could you direct me to the intensive care unit?"

"Yes I could," said Dr. Rabbit looking at his watch, "but I don't have time because I'm late for rounds in the intensive care unit."

"Well then, since I need to go to the intensive care unit may I come with you?"

"Yes of course. Why didn't you say so in the first place? Come along. Quickly now because we're already late."

She followed Dr. Rabbit down one hall, up an elevator, down another hall, through swinging doors,

thinking that it was all very wonderful, indeed.

"Is this the intensive care unit?" asked Alice in a reverent whisper.

"It says so doesn't it," said Dr. Rabbit pointing to the writing on the glass doors which said "TINU ERAC EVISNETNI" backwards though because they were now inside the unit looking out. "These patients are the sickest you ever saw. These doctors are the smartest in the world. These nurses know more than the doctors; well, they know a lot more than I do. Here technology triumphs over disease. Facts, not guesses. Nouns are better than adjectives. Numbers are the best kind of nouns. Here we can measure everything. With measurements we can do calculations. With calculations we can do logarithms. With logarithms we can solve any clinical problem."

"I thought it was algorithms," said Alice sheepishly.

"Algorithms, logarithms, it doesn't matter. It's all so very mathematical here. But now you see you've made me even later for ICU rounds." He scurried to the other end of the big room followed by Alice. They came up to a sizable group of people, all dressed like Dr. Rabbit, all facing the other way and looking rather nervous. Nothing was happening.

"What are they waiting for?" asked Alice.

"They're waiting for Dr. Queen of course. Dr. Queen and Dr. King, the attendings in the ICU this month. They know everything. They're so very mathematical."

Soon they appeared. Dr. Queen was clearly in charge. He was a short, fat, round-faced man with more hair in his eyebrows than he had on the top of his head, ears settled in near his shoulders. Neither his shirt nor his necktie quite came together under his chin, and Alice feared that the single button holding his shirt together just over his belt would break loose and hit her in the eye. He wore a rumpled white coat, the pockets of which held a stethoscope that he never used and the *Western Journal of Mollusk Research* that he never read. "What are you all waiting for, let's get going," he said in a croaky voice that was too whiny and too loud and provided to Alice the first evidence of what ultimately proved to be a thoroughly unpleasant personality.

Dr. King, however, was quite attractive for an older woman. She was tall and thin with proper Oxford shoes and half glasses that hung from a practical black cord around her neck when they were not on her nose,

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where she placed them on occasion to read numbers from the chart. She wore a starched, clean white coat, the pockets of which held a pen light that she used to read in dark conference rooms and a paperback edition of *Dr. Zhivago* that she was reading for the fourth time. "Yes, let's get going," said Dr. King benevolently.

"So who is presenting this first patient?" said Dr. Queen as they assembled at the first bedside.

"I am," said Dr. Rabbit who had taken up a position in front of the group. He pulled a card from his pocket and laid it on the large clipboard that held the record of the day's events and cleared his throat.

"Oh dear, so it's Rabbit," said Dr. Queen. "Please get it right today. Precise. Concise. Facts and observations. No editorials. Nouns, not adjectives. Carry on."

Rabbit thought to himself "nouns not adjectives, carry on," reciting the familiar directives. "Mr. Walrus is a 45-year-old carpenter who was injured in a motor vehicle accident last night. He presented in shock with fractured femur, fractured pelvis, and ruptured spleen. He was taken to the operating room where he underwent a laparotomy and splenectomy, and repair of fractured femur."

"To the operating room?"

"Yes Dr. Queen."

"Where did you think they were going to take out his spleen? In the hallway? In the elevator?"

"No sir."

"Anywhere else but the operating room?"

"No sir."

"Then why did you say he was taken to the operating room? We all knew that. Just say he had such and such injuries and underwent so and so operation. Carry on Rabbit."

"How very precise," thought Alice. "How very wonderfully precise and technical."

"After the operation he was brought here to the intensive care unit," said Dr. Rabbit, realizing too late that he had done it again. "Of course we all knew that he was brought here to the intensive care unit. I just thought I would point it out to everyone." Dr. Queen looked at the ceiling and tapped his foot. "Well here he is now. His blood pressure is 110/70, his pulse is 130 beats/min, his cardiac output is 3.5 L/min. His wedge pressure is 8, his central venous pressure is 4. His hematocrit is 30%. He's oliguric and cold and clammy. His systemic vascular resistance is one thousand seven hundred thirty four."

"1,734!" exclaimed Dr. King.

"1,734!" murmured all of the residents, accompanied by little inspiratory gasps and tutting of tongues.

"What a very high number," thought Alice. "1,734 is by far the largest number we have yet heard. Even Dr. Queen seems impressed. This is wonderfully scientific and mathematical."

"1,734 what?" asked Dr. Queen.

"1,734 dyne second cm to the -5th!" said Dr. Rabbit very, very proudly.

"Exactly," exclaimed Dr. Queen. "Down with the afterload! Measure the resistance, full speed ahead. Down with his afterload."

Alice, who had studied quite a lot of physics, felt somewhat confused. She turned to a tall man standing beside her whose name tag identified him as Dr. C. Pillar, Omnipotent and Omniscient Chief Resident. She tugged at his sleeve and whispered "Why did he say measure the resistance? You can't measure resistance."

Dr. Pillar's head and neck seemed to grow upwards out of his shirt collar and twisted down to look at her. "Whoooo are yooooou?" he queried, one arm rising, snakelike, from his side, unrolling through the air, and landing with his index finger on the tip of her nose.

"I'm Alice. I'm a medical student."

"I might have known," he said, finger, hand and arm, forehead, chin, and neck recoiling to their original positions. "What a naive question. Of course you can measure the resistance. It's 1,734 dyne second cm -5th."

"Excuse me sir but that's not true. All you can measure is pressure and flow. Resistance is just a calculation, not a measurement. It's just the pressure divided by the flow." Alice was somewhat surprised by her own temerity. But after all, everyone here seemed so interested in precision and accuracy. Dr. Pillar opened his eyes and his mouth widely as if preparing to respond, then closed both tightly as if thinking very hard. Alice thought she must have offended him. "At least that's the way it is in physics," she said, trying to be very polite (Fig 1).

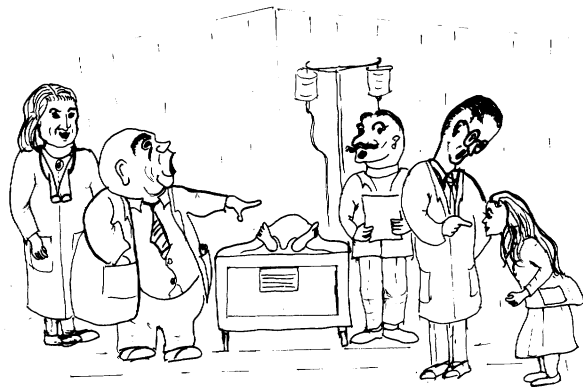


FIGURE 1.

"HMMMMMMMM. That's all yooooooooou know. This is high-tech intensive care medicine, not simple physics. HMMMMMMMMMMMM."

"Well I am very sorry, but physics is physics," said Alice more loudly and becoming a little indignant. "Pressure per flow. Millimeters of mercury per liter per minute. Measurements, then arithmetic. Mr. Walrus' blood pressure is 110/70. His blood flow is 3.5 L/min. Those are measurements. His resistance is 19 mm Hg/L/min in diastole and 31 mm Hg/L/min in systole."

"Says yooooooooou," sneered Dr. Pillar coiling and recoiling out of his shirt collar. "You can't have two resistances. Only one. And 31 is not nearly as impressive as 1,734."

"But he does have two resistances," said Alice. "In fact, he has continuously changing resistance because the arterial pressure and the venous pressure change all the time. This isn't like the physics lab at all. But still the principles ought to apply. This is very curious. Something's not right." Several residents in the group turned to hear this conversation.

"What's going on back there?" barked Dr. Queen, squinting at Chief Resident Pillar.

"This medical student can't understand how we measure systemic vascular resistance, that's all," said Pillar. "She thinks that the resistance changes continuously during the cardiac cycle. Haaaaaaaaaaaa."

"Down with her afterload" shouted Dr. Queen.

"Now let's think this through," said Dr. King calmly. "Technically she's correct. The arterial pressure changes continuously during the cardiac cycle, and the venous pressure changes continuously during the respiratory cycle. Not only that, the flow changes continuously during both the cardiac and the respiratory cycles. If we wanted to calculate the real resistance we would have to make the measurements every few milliseconds and that would leave us with hundreds of resistances during a single heartbeat."

"That's what I just said" exclaimed Alice, relieved to find someone who remembered simple physics coming to her support.

"Quiet back there. Down with the afterload," said Dr. Queen.

"That's technically correct but somewhat impractical," continued Dr. King. "So what we do is use the mean arterial pressure minus the mean right atrial pressure divided by the mean cardiac output which gives us a single number for calculated resistance. It's not very accurate, but it's a useful bit of bedside shorthand. So the resistance that we calculate for Mr. Walrus here is . . . What did you say the numbers are Dr. Rabbit?"

"Blood pressure 110/70 with mean pressure of 80. Right atrial pressure 4. Cardiac output 3.5 L/min."

"So you see," continued Dr. King, "the pressure gradient is 76 mm Hg and flow is 3.5 L/min. The simplified resistance calculation is 21.7 mm Hg for each liter of flow. Some people call that 21.7 Wood units."

"So it is physics after all," said Alice much relieved. "Arithmetic based on physics. But why did you say that the resistance is 1,734?"

"Because it is 1,734," said Dr. Queen, becoming impatient.

"It is 1,734" said all the residents, becoming nervous at Dr. Queen's impatience.

"Down with the afterload" said Dr. Queen.

"Down with the afterload" said the residents, anxious to please.

"But Dr. King just said that the resistance is 21.7. How did we get from 21.7 to 1,734?" asked Alice, becoming confused again.

"Why do we waste time on this trivia," said Dr. Queen. "Tell her Dr. Rabbit so that we can be on with our business."

"We multiplied 21.7×79.9 ," said Rabbit authoritatively. "That makes the resistance 1,734, give or take a few dynes. I think it's a very impressive number."

"But why do that?" asked Alice.

"We do it," explained Dr. King, "to convert from mm Hg/L/min to dyne second centimeters to the minus fifth." All the residents smiled and looked very smug. Most had forgotten this explanation but, having remembered, they were entitled to look very smug.

"Excuse me," said Alice meekly, "but that conversion factor applies to continuous flow of newtonian fluids like water through rigid tubes. Mr. Walrus has pulsatile flow of a nonnewtonian fluid flowing through elastic tubes. Besides, it's just more arithmetic. Why bother?"

"Why bother!" exclaimed Dr. Queen. "Because we're scientists."

"Because it makes a very big number," said Dr. Pillar.

"Because it's proper physics," said Dr. King.

"I guess I just don't understand," said Alice.

"That's because you're a medical student and we are important doctors. It takes yeeeeeeears to learn how to multiply by 79.9," sneered Dr. Pillar, his head nearly a foot out of his shirt collar. "It takes yeeeeeeears to learn to be a high-powered intensive care doctor. Hmmmmmmmmmm."

Hmmmmmmmmmm," murmured the crowd.

"Enough of this impudent interruption," said Dr. Queen. "Carry on Dr. Rabbit. What do you think we should do for Mr. Walrus here?"

Dr. Rabbit, very nervous, looked at the chart. He looked at the monitors, he looked at his fellow residents all trying to look inconspicuous. He was looking for Nurse Cheshire, who usually bailed him out of such crises. She was nowhere to be seen. The questions from Alice the medical student were vaguely disturbing to him. She seemed to make sense, and subconsciously he knew that there was something in that conversation that was pertinent to the care of Mr. Walrus. But he

couldn't quite put his finger on it. Dr. Queen was tapping his foot again, becoming impatient. "As I was saying," he began cautiously, sneaking looks at Dr. Queen, "his systemic vascular resistance is very high . . ."

"1,734," exclaimed Dr. Queen. Rabbit could tell that he was on the right track.

" . . . and I think we should do something about that very high resistance." Dr. Queen looked pleased for the first time today. Rabbit was encouraged. "No, I think we *must* do something about that very high resistance, that's what I think we must do," he said emphatically, taking a very large gamble that he might be right.

"Exactly Rabbit," croaked Dr. Queen. "Down with the afterload. Very good Dr. Rabbit. How shall we do that?"

"With an afterload reducing agent," guessed Rabbit.

"Yes, yes, the very thing! Which one? How much?"

"We could give him Thorazine, . . ." pondered Rabbit aloud, but Dr. Queen began to scowl, ". . . or isoproterenol," more scowling, ". . . or nitroglycerin," less scowling and a little nod, ". . . or nitroprusside." Dr. Queen smiled. Dr. King smiled. All the residents smiled. Even Nurse Cheshire who had mysteriously appeared behind Dr. Queen smiled widely. Rabbit had learned that Nurse Cheshire's smile might mean that he was correct, or might mean that he was totally incorrect.

"Nipride" exclaimed Dr. Queen. "How much?" Rabbit was at a total loss.

"We could give 10," he said, picking a neutral number out of the air. Dr. Queen's eyebrows went up instantly. "Ten is pretty high, don't you think, Nurse Cheshire?" said Queen, who, if the truth be known, wasn't quite sure of the dose himself.

"If Nipride is what he needs," smiled nurse Cheshire enigmatically, "maybe we ought to start with 5."

"Then 5 it shall be," said Queen. "Make up a standard drip and give him 5. Down with the afterload."

Rabbit was very relieved that he had picked a number which seemed to be reasonable, but he was very glad that Nurse Cheshire would make up the drip, because he didn't know 5 - what?

Alice was becoming confused again. She tugged at the bottom of Dr. Pillar's coat. "Excuse me. Won't Nipride lower his blood pressure?"

"Of course," whispered Dr. Pillar. "That's the very point of it."

"But the reason his resistance is high is because his cardiac output is so very low. Look at him. He's a big man. And he's had all of those injuries. He's anemic and oliguric. I don't know anything about intensive care, being just a medical student, but it seems to me that the right thing to do would be to raise his cardiac output."

"And how would you do that?"

"I'm not sure," said Alice thinking very hard, "Maybe he needs a blood transfusion."

"Haaaaaaaa," said Dr. Pillar, causing Alice to feel very small.

"What's going on back there," said Dr. Queen. "Is it that medical student again?"

"Yes," said Dr. Pillar. "She thinks that Mr. Walrus needs a blood transfusion, not an afterload-reducing agent."

"That's preposterous," said Dr. Queen. "His hematocrit is 30%. He doesn't need a transfusion."

"That's rather interesting," said Dr. King. "Young lady, why would you suggest a blood transfusion?"

"Because his cardiac output is low. That's why his resistance calculation is so high."

"But the normal cardiac output is 5 L/min," said Dr. King. "We all know that. His output is 3.5 L/min. Why, it's nearly normal."

"I learned in physiology that 5 L/min is normal cardiac output for an average man at rest. Mr. Walrus is a very big man who is not moving at all and rather cold. It just seemed to me that 3.5 L/min is rather low, considering the circumstances."

"You do have a point, young lady," said Dr. King, "Hemodynamic variables are usually standardized to height and weight, expressed as body surface area, which we call normalizing. Dr. Rabbit what is his cardiac *index*?" Dr. Rabbit hastily scanned the chart. Nurse Cheshire answered for him.

"It's 2.2 L/min per m²," she said without changing her smile.

"Well young lady. You are right. His cardiac index is a little low."

"I learned that the normal cardiac index is 3.2 L/min/m²," said Alice.

"That's normal over in physiology," said Dr. Queen, becoming exasperated. "Over here where the big boys play, anything over 2.2 we call pretty darn good perfusion. Besides we tend to focus on BP first and other stuff later. And his resistance is so very high! Down with the afterload!"

"That's another thing I've been thinking about," said Alice. "Shouldn't you use cardiac *index* to calculate resistance? After all, how could you compare the resistance in a big man like Mr. Walrus to a small man or a child? Surely the resistance doesn't change with the size of the patient, only the total number of resistance arterioles. There should be a way to compensate for that."

"There is," said Dr. King. "Since all adults are sort of the same size we get into the habit of using cardiac output for resistance calculations. But we really *should* be using cardiac index. The young lady is right about that. What's the systemic vascular resistance *index* Dr. Rabbit?"

"Well let's see," said Rabbit, scribbling numbers on the back of the ICU sheet, "Mean arterial pressure is 80 minus the CVP which is 4 gives 76 mm Hg pressure gradient divided by 2.2 L/min/m² gives us 34.5. 34.5 times 79.9 is . . . 2,757."

"2,757," shouted Dr. Queen. "It's even higher than we thought. Quick Nurse Cheshire, up with the Nipride, down with the afterload."

"But but but," sputtered Alice.

"No more wasting time. Do it Nurse Cheshire and we'll come back after rounds to see how very effective our treatment is. On to the next!"

•••

The next patient was a little old man who was sitting up in bed. On the table in front of him were a cup of tea and a cracker in a cellophane envelope. Alice observed that he looked yellow and had very big legs for such a small man.

"This is Mr. Madder," began Dr. Rabbit.

"Hatter. Not Madder," said the patient.

"Yes. This is Mr. Hatter. How are you feeling Mr. Hatter?"

"Not bad."

"Mr. Hatter was not a patient until 2 months ago, when he developed a nonproductive cough and a nontender swelling in his neck. A noninvasive needle biopsy specimen showed that he has non-Hodgkin's lymphoma. He was treated nonoperatively with chemotherapy. His initial response was not too bad but now he is a nonresponder. Last week he developed abdominal pain and radiographs showed nonvisualization of the gallbladder because of acalculous cholecystitis. Last week he underwent a laparoscopic non-laparotomy cholecystectomy. He was not admitted to the hospital after that procedure but was sent home on a regimen of nonsteroidal drugs. He came in 2 days later with fever, chills, jaundice, and nonoliguric renal failure. We worked him up for non-A non-B hepatitis which he did not have. Yesterday he became short of breath and we admitted him to the ICU with a diagnosis of noncardiogenic pulmonary edema. Since he has been here we have determined that he has non-insulin-dependent diabetes but does not have nonosmotic, nonketotic acidosis. He does, however, have a negative base excess."

Alice was very impressed by this scholarly presentation. It seemed to her that Dr. Rabbit had explained what was wrong with Mr. Hatter by describing all the things which he did not have. She thought how very difficult it must be—no, she thought how it was not easy—to develop this unusual method of syntax. Everyone on rounds seemed quite content—no, not uncontented with the presentation.

"Numbers. Tell us numbers," insisted Dr. Queen.

"His blood pressure is 110/70, his CVP is 4, and his

wedge pressure is 8. His cardiac output is 8 L/min. His . . ."

"Dr. Rabbit," interrupted Dr. King, "what is his cardiac *index*? We're trying to be a little more scientific today."

Nurse Cheshire appeared at the foot of the bed, grinning at this new effort at normalizing. "His cardiac index is 8 L/min," she said.

"Yes, 8 L/min cardiac index," said Dr. Rabbit quickly.

At this point Mr. Hatter, who had been looking very still and somnolent, raised his saggy eye lids and looked at Alice. "Now here's a riddle," he said. "How could my cardiac index be 8 L/min when my cardiac output is 8 L/min?"

"Yes. How could it?" said Dr. Queen. "That's impossible."

"Can't be done. Must be a mistake," said Dr. Pillar.

"Well Alice," said Dr. King, "do you have an answer for the riddle?"

Alice thought very hard. Then she said, "If his estimated body surface area, based on his height, weight, age and sex, comes out to 1 m², then his cardiac output and cardiac index would be the same."

"I do believe she's right," said Mr. Hatter who had been an expert on numbers before he became ill.

"Indeed she is right," said Dr. King. "Therefore his systemic vascular resistance *index* is 80 minus 4 equals 76 mm Hg divided by 8 equals 9.5 Wood units. That makes his systemic vascular resistance index about . . . 760 dyne second centimeters minus fifth."

"Only 760!" exclaimed Dr. Queen.

"Only 760!" murmured all of the residents, accompanied by little inspiratory gasps and tutting of tongues.

"What does that mean?" asked Alice, recognizing a look of shock and a look of chagrin and distaste and fear on the face of all the residents.

"Shows what yooooooooooooou know," said Dr. Pillar. "It means that he's . . . SEPTIC."

"This is very scientific," said Alice. "Just from arithmetic you can tell that he is septic?"

"We certainly suspect it in any patient who has a low systemic vascular resistance," said Dr. King. "But tell us Dr. Rabbit, what are the rest of the numbers?"

"His systemic vascular resistance *index*," said Dr. Rabbit, putting special emphasis on index with a little sneer toward Alice, "is 759.05 dyne second centimeters minus fifth. His temperature is 39.4°C. His white blood count is 25,000. His bilirubin is 6.6. His hematocrit is 25% and hemoglobin 7.9 g/dL. His Vo_2 is 160 mL/min m²."

"What's Vo_2 ?" Alice asked of Dr. Pillar, quietly.

" Vo_2 is the abbreviation for oxygen consumption per minute. We measure the amount of oxygen consumed across the lungs by having the patient breathe into a spirometer. We measure it at the lungs but the num-

ber is exactly the same as the amount of oxygen consumed in metabolism of all the tissues. The normal amount is about 120 mL/m²/min, so Mr. Hatter at 160, is very hypermetabolic. It's another sign of sepsis."

"His PO₂ is 95, his saturation is 99%, therefore his DO₂ is 850 mL/min," continued Dr. Rabbit.

"What's DO₂?" Alice asked of Dr. Pillar

"It's the abbreviation for oxygen delivery per minute. It's autoregulated to about five times consumption. You take the oxygen content—that's the hemoglobin times arterial saturation times 1.34 mL O₂ per gram Hb (that's 10.6 mL/dL for Mr. Hatter)—times the cardiac output in deciliters—that's 80 for Mr. Hatter—and it comes out around 850 mL/O₂ delivered to systemic tissues per minute. Normal oxygen delivery is about 600 mL/m²/min. His DO₂ is elevated in response to his increased metabolic rate."

"His PO₂, as I said, is 95, his PCO₂ is 35, and his pH is 7.40," continued Dr. Rabbit. His pulmonary artery pressure is 30/6 with a wedge of 8. That's after we've given him 6 L of saline solution today. His heart rate is 140 and his mixed venous oxygen saturation is 80%."

"Just goes to show you how useless that SvO₂ monitor is," said Dr. Queen. Here he is in septic shock with low systemic vascular resistance requiring huge amounts of fluid and the dumb SvO₂ is 80%."

"Yes, just goes to show you what a dumb monitor that is," repeated Dr. Rabbit, anxious to please.

"Goes to show you how the SvO₂ is artifactually high in sepsis. What a dumb expensive monitor."

"Goes to show you," echoed Dr. Rabbit.

"May I ask a question," said Alice from the back of the group.

"Oh dear, it's the medical student," said Dr. Queen.

"Now what do we have to explain to you?"

"I've just been doing a little calculating," said Alice who had studied quite a lot of mathematics. "If the oxygen delivery is 850 mL/min and the oxygen consumption is 160 mL/min, only 19% of the oxygen is removed in the process of metabolism. If the arterial blood is 99% saturated, then the mixed venous blood should be 80% saturated which is exactly what it is. Why then, is SvO₂ a dumb monitor?"

"It's dumb because it doesn't correlate with oxygen consumption," said Dr. Queen looking exasperated.

"It doesn't correlate with oxygen delivery," said Dr. Rabbit.

"It doesn't correlate with cardiac output," said Dr. Pillar.

"But I don't think it should correlate with any of those," said Alice. "It should correlate with the relationship between oxygen consumption and oxygen delivery. That's all."

"She's right of course," said Mr. Hatter, rather sleepily.

"Yes I do believe she's quite right," said Dr. King.

"Perhaps it's not such a dumb monitor after all. Actually, it tells us a lot about Mr. Hatter here."

"Here's another riddle," said Mr. Hatter. "If the SvO₂ monitor is useless you should less use it. If you don't understand it, you shouldn't stand under it. When should you use it more?"

"I believe I know the answer," said Dr. King. "If you understand what the SvO₂ measures you'll use it more."

"Quite so," said Mr. Hatter.

"Well I don't understand this whole conversation and I think it's useless," said Dr. Queen emphatically.

"I know. Woe is me," said Mr. Hatter returning to his teacup.

"Dr. Rabbit," said Dr. Queen, ignoring the impolite patient, "what do you think we should do about the oxygen delivery for Mr. Hatter? Have you read all the recent papers about supranormal and maximizing oxygen delivery?"

"Yes of course," said Rabbit proudly. "Actually Mr. Hatter's oxygen delivery is already over 600 mL/m²/min. I suppose that's supranormal. We could give him packed cells or inotropic drugs to make the DO₂ even higher but I'm not sure we need to. His cardiac output has compensated for his anemia very well. I would say that his systemic oxygen delivery is appropriate for his level of metabolism."

"I'm beginning to understand," said Alice. "The cardiac output normally increases in response to increased metabolic rate, or anemia, or hypoxia, to keep the DO₂ about five times VO₂."

"Yes, you are right," said Dr. King, "And if the heart can't compensate normally, we help it along with inotropes or packed cells. Shoemaker has been saying that for years, and it turns out he was right all along."

"That's all well and good," said Dr. Queen, "but how about oxygen radicals? All of this infection is going to lead to white cell activation which causes peroxide and superoxide radicals which oxidize the lipids and consume the antioxidants. If it gets too much oxygen he'll make too many oxygen radicals."

"It seems to me," volunteered Alice, "that those two phenomena are unrelated. Oxygen delivery and consumption are in the metabolism category and oxygen radicals are in the host defense category. Seems to me they're quite unrelated, except that patients who are septic will have an increased metabolic rate requiring more oxygen delivery."

"Shows what yooooooooooooou know," sneered Dr. Pillar.

"Actually it is somewhat confusing," said Dr. King. "Rather like the confusion associated with giving lactated Ringers solution to patients who have lactic acidosis. Fortunately we have a consultant from Infectious Disease who can settle this issue for us. It's Dr. Dumpty."

The residents pulled aside so Dr. Dumpty could waddle up to the bedside. Dr. Dumpty had an ovoid habitus which began at the top of his pointy head, reached maximum dimension somewhat inferior to his belt line, and came together again at the level of his custom-made orthotic shoes. He teetered from side to side as he talked, and the residents had the feeling that he would fall over, but he never did. He wore a coat made of white canvas that had originally been a four-man wall tent in the pocket of which were 22 laminated handouts from drug representatives describing the dosage for a variety of expensive antibiotics.

"Dr. Dumpty," said Dr. Queen. "We were discussing oxygen delivery in the face of various metabolic rates, and someone brought up the fact that neutrophils kill bacteria by generating radicals of oxygen. Could you clarify those issues for us?"

"It's very simple," said Dr. Dumpty, gently rocking back and forth. "I summarized it in a recent editorial which I will read for you now." He pulled a crumpled sheet of paper from his pocket, smoothed it out, cleared his throat and began to read:

Jabberwoxy

'Twas septic and the slimy rods
Did gyre and gimble in the blood.
All mimsy were the neutrophobs
More air to fuel the flaming flood.

Gramneggars sting and conflagrate
The neutrophobs perfuse acquire
Good oxygas to generate
a Jabberwox to feed the fire.

With vorpal sword well catalyzed
by iron and selenium
Jabberwox killed bugs despised
and mayhaps endothelium.

Dilemma lacking common sense
A preconcepted man could make
On Jabberwoxy evidence
A categorical mistake.

So good or bad it has become
A scientific fadical
For most of academicum
To ridicule the radical.

'Twas septic and the slimy rods
Did gyre and gimble in the blood.
All mimsy were the neutrophobs
More air to fuel the flaming flood.

After the reading of the editorial the entire group was silent, looking from one to another. Mr. Hatter had fallen asleep and was snoring. "Hmmmmmmm," said Dr. Pillar.

"Hmmmmmmmmm," said all the others.

"Brilliant. Exactly what I had thought," said Dr. Queen.

"I don't understand at all," said Alice. "Would you explain it to me Dr. Queen?"

"Yes Dr. Dumpty," said Queen, "Would you explain it to our medical student here?"

Dr. Queen seemed very pleased to pass along the question, since he, in truth, had not understood the poem at all.

"It's very simple," said Dr. Dumpty. "To interpret this poem (rather like the stories of Lewis Carroll) it's necessary to understand the philosophers and the pop culture of the times in which it was written. Ryle defined category mistakes. And mimsy means upregulated."

"Oh" said Alice. Everyone else looked so condescendingly secure that she decided not to ask any other questions (Fig 2).

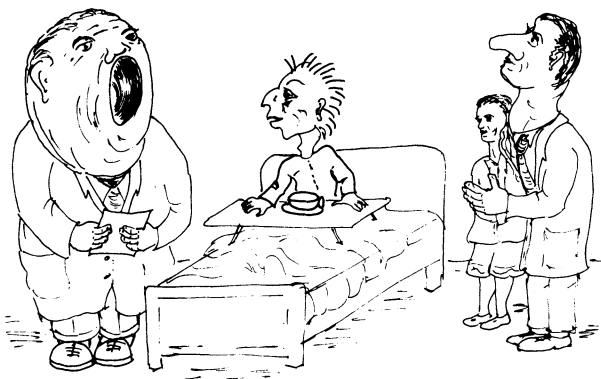


FIGURE 2.

"Perhaps I can help." The speaker was a tall business-like looking man with a hooked nose. His name tag said Dr. Griffin-Surgery. "The superoxide and hydroxyl radicals that are generated by activated inflammatory cells injure endothelial cells in tissue culture. But in real patients those radicals combine instantly with chloride and proteins to make innocuous hypochlorite, chloramines, and a few other molecules. Everyone interested in shock and inflammation has been trying to tie this phenomenon to multiple organ failure but it never quite fits together. The whole process has nothing to do with the physiology of systemic oxygen kinetics, and it is totally unrelated to FI_{O_2} . Isn't that what you meant Dr. Dumpty?"

"That's a basically accurate but naively oversimplified summary of what I said," sniffed Dr. Dumpty, teetering dangerously close to off balance.

"Dr. Griffin is the surgeon who is consulting on Mr. Hatter," said Dr. King. "Dr. Griffin, we've just been discussing Mr. Hatter's case. What do you recommend? Up the afterload? Up the preload? More oxygen delivery? Less oxygen delivery? Another gallon of Ringers?"

"None of that," said Dr. Griffin. "He needs a little operation to drain the abscess in his right upper quadrant."

Dr. Queen had to bite his tongue to avoid laughing out loud at this old-fashioned suggestion. Most of the residents looked aside or brought their hands to their face so as not to appear impolitely amused.

"Surely you meant to say a CT scan followed by an endoscopic retrograde cholangiopancreatography (ERCP) followed by a percutaneous tube or two or three," said Dr. Queen, when he could speak without sniggering.

"Surely you mean an operation if our most expensive antibiotics fail," said Dr. Dumpty, teetering.

"Suuuuuurely you mean possible operation after his hyperdynamic septic state has been resolved," said Dr. Pillar.

"No, what I meant was to do a little operation to drain the abscess in his right upper quadrant. He's septic, febrile, has a tender mass, and is 4 days following a cholecystectomy."

"We will certainly keep that wise advice in mind, Dr. Griffin. In the meantime, Dr. Rabbit, what do you have planned for this afternoon for Mr. Hatter?"

"He is scheduled to have a CT scan followed by an ERCP with papillotomy, fluoroscopic exploration for retained stones, and placement of a stent if he has a bile leak."

"Sounds very modern," smirked Dr. Queen. "I'm sure that Dr. Griffin will be standing by." Dr. Griffin merely nodded.

"Woe is me," murmured Mr. Hatter.



"Our next patient," said Dr. Pillar, leading the group to the next bedside, "has ARDSsssssss. The case will be presented by Dr. Knight." Dr. W. Knight was one of the oldest residents anyone could remember. He had been out in general practice for a number of years, then took time out to get an MBA, then became the administrator of a small hospital which subsequently closed, then took a radiology residency, and was now taking a year of critical care medicine. He spent most of his time trying to master modern ventilators, but was still having a hard time of it. He had a long droopy white mustache and wore a wrinkled scrub suit and carried a backpack in which he had the full volume of *Civetta's Critical Care*. In a rather melancholy voice, he described the patient.

"Mr. M. Fibian presented to us a week ago with acute severe respiratory failure that we assumed to be viral pneumonia. He was intubated and has been on a ventilator for a week. He progressed from pneumonia to ARDS 3 days ago."

Alice wondered what this meant. She had been

taught in pathology that ARDS was a clinical syndrome of leaky pulmonary capillaries following shock, trauma, or sepsis. She thought that pneumonia was pneumonia and ARDS was reserved for conditions in which the basic problem was extrapulmonary. However, she was beginning to learn not to ask naive questions, so she simply listened.

"Mr. Fibian's blood pressure is 110/70 mm Hg. His CVP is 4 and his wedge is 8. His cardiac index is 3.2 and his systemic vascular resistance index is 24. You could also describe that as 1,900 dyne second centimeters to the minus fifth per square meter."

"At last, a patient with normal resistance," said Dr. King contentedly.

"Maybe we should drop his afterload anyway," suggested Dr. Queen.

"No I don't think so," said Dr. King. "Carry on Dr. Knight."

"He's paralyzed with pancuronium to keep him on the ventilator. His oxygen consumption is 100 mL/m²/min and his oxygen delivery is 400 mL/m²min. His arterial saturation is 95% and his venous saturation is 70%."

"His DO₂ is only four times VO₂," observed Alice. "Does that mean there's not enough oxygen delivery?"

"No," said Dr. King. "There's a large delivery reserve. The critical low level of DO₂ is two times VO₂. Below that anaerobic metabolism, acidosis, and oxygen debt occurs. We call that being 'supply dependent.'"

"Let's decrease his afterload to increase his delivery," suggested Dr. Queen. "He has ARDS so he must be *pathologically* supply dependent."

"No, that idea has finally been laid to rest," said Dr. King. "The idea of pathologic supply dependency was mostly artifact that resulted from studying patients on the knee of the oxygen kinetics curve, and from mathematical linkage of the variables. Besides his oxygen delivery is perfectly adequate for his level of oxygen consumption. Just look at his SvO₂."

"Oh Dr. King," said Dr. Queen, sotto voce, "I love it when you talk physiology." Dr. King did the older woman equivalent of blushing and motioned to Dr. Knight to continue.

"He's receiving volume-limited ventilation at 10 mL/kg. His PEEP is 10 and his peak inspiratory plateau pressure is 50. The FIO₂ is 0.7 and the rate is 20. With those ventilator settings we're able to keep his PCO₂ at 40, his pH is 7.5, and his PO₂ is 70 with 95% saturation on the pulse oximeter."

"Nice normal blood gases! A little hypoxemic but otherwise normal blood gases. Very nice job Dr. Knight," said Dr. Queen.

"In physiology they taught us that the alveoli are fully inflated when inspiratory pressure is 35 cm H₂O," said Alice. "What happens when you stretch them up to 50?"

“Stop interrupting,” shouted Dr. Queen. “This isn’t physiology, it’s mechanical ventilation! Carry on Dr. Knight.”

“Thank you,” said Dr. Knight. “I’ve been practicing and practicing with mechanical ventilators to try to make the blood gases normal. It’s not too hard if you just use enough pressure and enough oxygen.”

“I do believe you are getting the hang of it Knight,” said Dr. Queen. “What’s that plastic tube sticking into his side?”

“He had a pneumothorax a few days ago, so we put in a chest tube. I didn’t mention that we had to turn the tidal volume up to 900 mL to get our 700 mL exhaled tidal volume (Fig 3).”

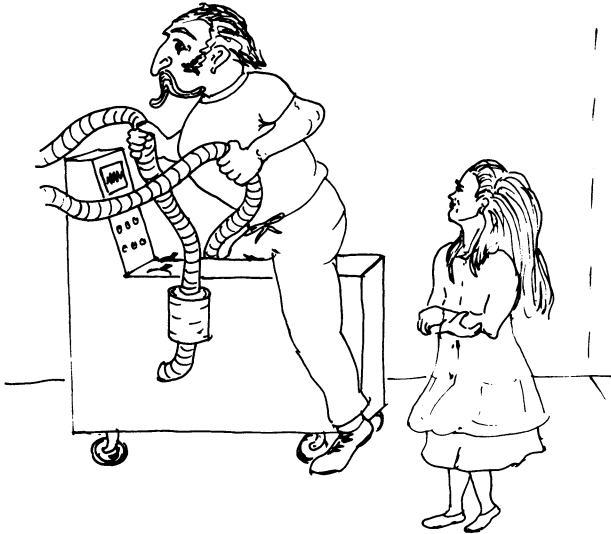


FIGURE 4.

“Good planning,” said Dr. Queen. They all nodded.

“With regard to nutrition,” continued Dr. Knight, feeling more self-confidence, “he’s never had any bowel sounds—probably because of all the morphine we’re giving him—so after a few days we decided to give him total parenteral nutrition (TPN). The next day we got a central line in and wrote some orders. Yesterday we gave him half dose and today he’s up to full strength—2 L/d of TPN solution. That gives him 2,000 calories of sugar and 80 g of protein per day. That, plus his maintenance fluids and the drips for antibiotics and morphine and pancuronium adds up to about 4 L/d. Maybe that’s why he’s 8 kg over his admission weight.”

“That sounds like excellent care Dr. Knight. How do you decide on the amount and composition of the TPN solution? Did you measure his oxygen consumption and calculate his caloric requirements? Did you measure his urinary protein and calculate his protein catabolic rate?”

“No. We just looked it up on a table. Actually the nutrition people looked it up and told me to give him 2 L/d of the standard stuff. It does seem to be helping

though, because his serum albumin has leveled off at 2.4 g/dL.”

“Here’s his radiograph,” said Dr. Knight, pointing to the AP chest film taped on the window. “Notice that he has diffuse bilateral fluffy pulmonary infiltrates.”

“Excuse me sir,” said Alice. “I’m just a medical student, but isn’t all that white stuff on the chest x-ray film mostly water?”

“Why yes it is,” said Dr. Knight in a patronizing fashion.

“If he has all that water in his lungs, and he’s 8 L over his admission weight, isn’t that what they call fluid overloaded?”

“Haaaaaaaa,” said Pillar, snorting derisively.

“Haaaaaaaa,” said all the other residents.

“You see, young lady,” explained Dr. King, “His wedge pressure is 8 so he can’t possibly be fluid overloaded. In fact he’s probably a little on the dry side.” They all nodded knowingly.

“But that doesn’t make sense,” insisted Alice. “The wedge pressure is only dependent on the left ventricular function and the central blood volume. It’s not a measure of extracellular fluid volume. If he’s 8 L ahead his extracellular space is almost twice normal. Look at him. You can see he’s edematous. And his lung is edematous. You can see that on the x-ray film. I suppose there’s some minor connection between chronic changes in the extracellular space and the function of the left ventricle but they really are quite independent, and not at all measured by the wedge pressure.”

“This is preposterous. Down with her afterload,” said Dr. Queen. “Where did they teach you that stuff?”

“Right here in our medical school,” she answered meekly. “We spent a whole year studying physiology and anatomy and several months studying cardiopulmonary pathology.”

“What’s the matter with those basic science people?” said Queen. “Didn’t they ever hear of Starling and Pappenheimer and Landis and Sarnoff and Fishman and Staub?”

“Why yes,” said Alice brightly, “those were just the names they mentioned. This is all very curious, very curious indeed.”

“I believe she does have a point,” said Dr. King cautiously.

“Poppycock. Preposterous. I suppose next she’ll be suggesting concentrated albumin. And a diuretic. With a low wedge pressure! Preposterous. Carry on Dr. Knight. What are your plans for riding that ventilator?”

“I am a little worried about the hypoxemia with a PO_2 of 70. I can’t decide whether to increase the tidal volume or the PEEP or the FIO_2 . I do a best PEEP curve every day, that’s how I decided on 10.”

“Dr. Knight, explain to our curious medical student how you do a best PEEP curve. I’m sure they didn’t teach her that over in physiology.”

"We hold the tidal volume constant and change the PEEP up and down between 5 and about 20. We measure the cardiac output and the PO_2 at each level of PEEP and pick the level where the PO_2 is highest, but lower than the level that causes the cardiac output to fall. That's the best PEEP for the day."

"You mean you measure the point of highest systemic oxygen delivery in relationship to the metabolic rate?" asked Alice.

"When you put it that way, that's exactly what we do. Finally you're catching on," smirked Dr. Queen.

"Then why don't you just measure the SvO_2 continuously and pick the PEEP level that corresponds to highest SvO_2 . Isn't that the same thing but simpler?" asked Alice.

"Oh dear, oh dear," said Queen looking very exasperated.

"And while we're on it," said Alice "Why do you hold the tidal volume constant? It seems to me that would lead to disproportionately high peak airway pressures as you go to higher levels of PEEP because of the shape of the compliance curve. Not only that, the mean airway pressure would go up disproportionately, limiting venous return inappropriately. Wouldn't it be better to limit the peak airway pressure to some safe level then change the PEEP, allowing a variable tidal volume but avoiding high pressure over distention?"

"Shows what yooooooooou know," interrupted Dr. Pillar. "When the tidal volume goes down he'd get more hypoxic."

"No, the tidal volume is not related to oxygenation. I'm sure of that," said Alice. "He might get hypercapnic, but increasing or decreasing the tidal volume won't affect arterial oxygenation."

"How about that Dr. Knight," said Dr. King who had begun to think that Alice might be right. "Have you tried permissive hypercapnia? It's all the very latest thing you know."

"I've tried Dr. King, but I just can't seem to get his PCO_2 much over 45. Actually when I raised the PEEP to 20 for a few hours yesterday, the PCO_2 got up to 50 but he stopped making urine and the air leak increased. The peak airway pressure was about 65. I don't understand what's so great about this permissive hypercapnia stuff."

"Actually," said Dr. King, "I believe the point is to limit the peak airway pressure below 40 to minimize the risk of overdistention, and to tolerate hypercapnia if it results. Alice is correct, because the shape of the volume-pressure curve is the same for a single alveolus or a whole lung. There never is any benefit to raising the alveolar inflating pressure above 35. Anything else just overdistends the most normal alveoli in the lung. We really must pay more attention to barotrauma. Or volutrauma, or stretch trauma, call it whatever you like."

"But this ventilator will generate pressures up to 100 cm H_2O ," said Dr. Knight. "I've spent a whole month learning how to adjust the pressure and flow to get 10 mL/kg tidal volume."

"Maybe that's your problem," said Alice, mostly to herself but too loudly.

"That does it," shouted Dr. Queen, all red in the face. "This concludes our rounds. Young lady you are the most annoying medical student that I've met in years. You come in here with no experience and ask the most naive questions about things that we do every day to save lives. You are excused. Don't come back until you're more properly prepared for real clinical physiology. Goodbye." They all turned to walk away, but by now Alice had decided to have her honest say.

"Now just a minute," said Alice emphatically. "I may be just a medical student, and I know that this hospital is a Wonderful Place, and I know you're all very experienced. Most of what you do here is wonderful, but it's not mysterious."

"Hold your tongue," said Dr. Queen turning purple.

"I won't," said Alice.

"Down with her afterload," Dr. Queen shouted.

"Stuff and nonsense," said Alice. "It's plain to see that some of the things you do are silly, or just traditional, and some are fuzzy thinking. Some of the things you do lack common sense and some are downright dangerous. Even I can see that. And furthermore you're not very polite. You're nothing but a pack of . . . clinicians!" And with that she left the hospital via the long tunnel that led back to the medical school (Fig 4).



FIGURE 3.

Alice was sitting on a stool in the Physiology Lab with her lab partner. They had a dog under anesthesia on a mechanical ventilator and had placed a variety of monitoring catheters. Alice had learned many valuable lessons during her visit to the ICU, and tested them out on her dog. At the end of the experiment she wrote down her observations in her lab notebook.

1. Always use cardiac index to calculate systemic or pulmonary vascular resistance. If the resistance is abnormal, treat the cardiac output or the pressure, not the resistance.
2. Oxygen delivery should be four to five times oxygen consumption regardless of the metabolic rate. Usually, cardiac output autoregulates DO_2 to compensate for anemia, hypoxia, or change in metabolic rate. Continuous SvO_2 is the best way to monitor all the variables of oxygen kinetics simultaneously.
3. Wedge pressure is *not* a measure of extracellular fluid volume. Wedge pressure *is* a measure of cardiac function related to blood volume.
4. Hypercapnia is safer than hyperinflation.

To her lab partner she said, "This all seems very simple in our dog experiment, but you wouldn't dream how very complicated it is in the ICU, or perhaps you would only dream it. And bye-the-bye," she added as an afterthought, "when you go there, my advice is to keep your eyes and ears open and your mouth shut, if you want to be a successful medical student."

•••

Dr. Rabbit and Dr. Knight spent most of their time in the ICU during the 2 weeks after Alice's visit. Mr. Walrus's condition improved after 5 U of blood. Nurse Cheshire never gave the Nipride, claiming that the

pharmacy was out of it. Mr. Hatter developed necrotizing pancreatitis after the ERCP. He had several operations including drainage of a subphrenic abscess but died after 10 days. The cause of death was listed as pancreatitis. Mr. Fibian developed a large bronchopleural fistula that made it impossible to maintain his peak airway pressure greater than 30 cm H_2O . As a result, his PCO_2 hovered around 70 for 3 weeks. He never got more than 50% oxygen because Nurse Cheshire said that the hospital supply was running low. His arterial saturation was 80 for 3 weeks. Then he recovered rather nicely and returned to his job making oyster stew in a soup kitchen.

•••

Dr. Queen rotated off-service, quite exhausted, and went back to 11 months in his well-funded laboratory to study the expression of upregulated cytokine receptors on eosinophils in nasal mucus. The correlation between clinical oxygen kinetics and substrate-limited events in his Petri dishes never occurred to him. Dr. Pillar conducted a nice clinical study on diuresis, fluid balance, transfusion, and left ventricular function in ARDS patients. By the time the manuscript was finished, he was quite convinced that it was all his idea. Dr. W. Knight had finally mastered volume ventilation when Dr. King announced the unit policy limiting PIP to 35, requiring him to start learning all over again. Dr. King also put SvO_2 monitors at every bedside because she read it was cost-effective. One day, months later, she said to Nurse Cheshire, "Do you remember when we used to make such a fuss over resistance?"

"I try not to," said Nurse Cheshire.

"Why did we do that?" asked Dr. King.

"A matter of mathematics over common sense," said Nurse Cheshire with a grin so wide that the rest of her seemed to fade away (Fig 5).

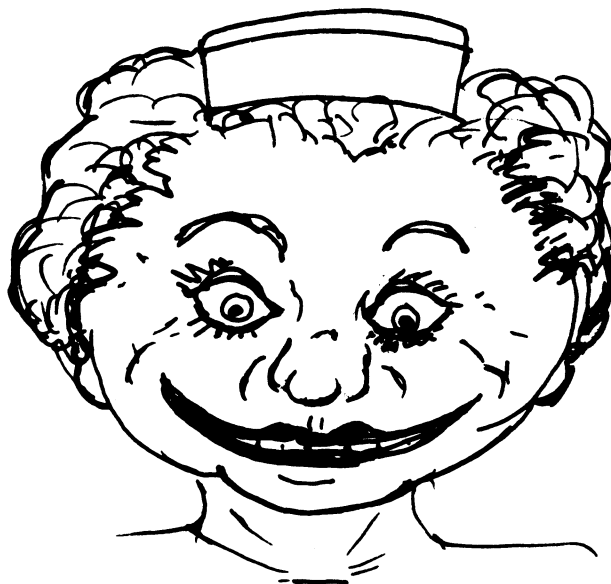


FIGURE 5.

Alice in Intensiveland
Robert H. Bartlett
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