NATIONAL CENTER FOR CASE STUDY TEACHING IN SCIENCE

Cardiac Imaging Using a Radioisotope:
A Concrete Application of Nuclear Chemistry

by

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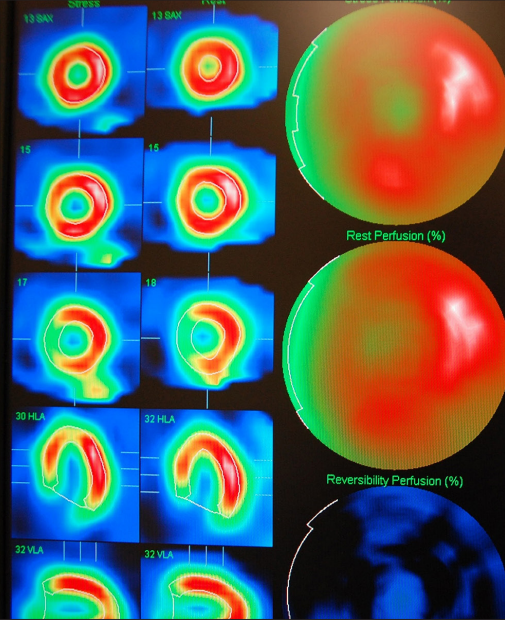

Mr. Carleton, a 49-year-old science teacher, typically enjoyed his daily 30-minute walk to school. He usually felt good during the exercise in spite of his history of obesity, hypertension, high cholesterol, and prediabetes. However, last week, he noticed mild chest pain that occurred during his walk. As a result, he decided to visit his cardiologist, Dr. Owusu.

"How have you been feeling, Mr. Carleton?" asked Dr. Owusu.

"I'm doing okay. However, I noticed mild chest pain that sometimes happens when I do my daily walk outside," explained Mr. Carleton. "At first, I was hesitant to see you before my scheduled six-month visit, but my wife pleaded with me to have this evaluated."

'It's good that you came," said the doctor as she measured his blood pressure and heart rate. She then placed her stethoscope on the patient's chest and listened to his heartbeat.

"Your vital signs and physical exam are reassuring, and I know from recent blood tests that your cholesterol levels are now under control. Please stay here. The medical assistant will prepare you for an electrocardiogram (EKG) to assess the electrical conduction system of your heart. I'll be back to go over the results," the doctor explained.

The medical assistant later placed the EKG leads on Mr. Carleton and obtained an EKG. After a while, Dr. Owusu returned, studied the EKG, and reassured Mr. Carleton. "Your EKG does not show any abnormalities. However, I would like you to return in two weeks for a nuclear stress test."

"Is this similar to the stress test I've had in the past?" inquired Mr. Carleton.

"Yes, it is the same stress test, but we will also administer a radioactive substance that will help us see how well blood flows through all parts of your heart and if there are any areas of concern," replied the doctor.

"Which radioactive source will be used and how much radioactivity will I be exposed to?" asked Mr. Carleton.

"As a science teacher, you'll have a good understanding of the nuclear chemistry that makes this imaging possible. You will initially be given 10 millicuries (mCi) of technetium–99m, and we will take a scan that should tell us how well blood flows throughout your heart when you are resting," explained Dr. Owusu.

"That sounds OK," said Mr. Carleton.

The doctor continued, "It is also important to see if all parts of your heart are getting adequate blood flow with moderate exercise, so two hours later we will repeat the test while you are walking on a treadmill. We will inject technetium 99-m when you reach peak exercise levels while jogging. Throughout the process, your heart's rhythm and other vital signs will be monitored to ensure all is well."

"How much technetium will be given during peak exercise?" asked Mr. Carleton with concern.

"For this part of the test, a higher dose is needed. You'll be given 27.5 mCi, about three times the original dose," replied the doctor.

Mr. Carleton did not seem reassured, so Dr. Owusu continued, "The radioisotope breaks down to half its amount every six hours, so not much is left in a day's time. In addition, about 60% of it leaves the body in your urine and feces."

"What happens to the rest?" asked Mr. Carleton.

"That gets incorporated into your skeleton. But don't worry, it's converted to a form that gives off negligible radioactivity," explained Dr. Owusu.

Mr. Carleton remained quiet for a while, so Dr. Owusu asked him, "Do you have any additional questions?"

"Is there anything I need to do before the test? Also, are there things I should avoid?"

The doctor replied, "I've asked the receptionist to give you a list of do's and don'ts prior to the test, which many people find to be helpful. Of course, reach out with any questions that may arise."

"Who will be conducting the nuclear stress test?" asked Mr. Carleton.

"I will. In addition, I'll be assisted by a nuclear pharmacy technician and a nurse," assured Dr. Owusu.

"Thanks. I'll see you in two weeks at 6.00 a.m.," Mr. Carleton promised.

Over the years, Mr. Carleton had developed a rapport with Dr. Owusu and found her to be a competent and caring cardiologist. Initially, he had been worried about possible long-term negative health impacts of testing, but he now felt reassured by her explanation and he planned to review the nuclear chemistry aspects of his imaging.

Questions

1. Using suitable equations, explain the difference between a chemical reaction and a nuclear reaction.

2. Using suitable examples, explain what is meant by an isotope.

3. Using suitable examples, explain what is meant by a radioactive isotope.

4. Write the symbol for each of the following forms of radiation: alpha particle, beta particle, and gamma ray.

5. For alpha particles, beta particles and gamma rays, compare:
   a. The approximate distance travelled in air by each particle.

   b. The approximate depth of tissue penetrated by each particle.

   c. The shielding required to protect from each particle.

6. In a nuclear reaction, the sum of the mass numbers and the sum of the atomic numbers on one side of the equation must equal the sum of the mass numbers and the sum of the atomic numbers on the other side. Complete the following nuclear equation:

   $^{42}_{19}\mathrm{K} \rightarrow \ ? + {}^{0}_{-1}e$

7. Explain what is meant by each of the following: curie (Ci), rad, and rem.

8. Why does radiation at a high enough dose cause biological damage and thus radiation sickness? Why is there more damage to rapidly dividing cells?

9. Using a suitable example, explain what is meant by the half-life of a radioisotope.

10. The half-life of I-123 is 13 hours. How much of a 50.0 mg sample of I-123 remains active after 52 hours?

11. Why is the half-life a major consideration when determining the appropriateness of radioisotopes for imaging?

12. Explain what other considerations are likely used to determine the appropriateness of radioisotopes for imaging.

13. Technetium-99m is produced in many hospitals. Complete the following nuclear reaction and indicate the element from which technetium-99m is derived.

    $? \rightarrow {}^{99m}_{43}Tc + {}^{0}_{-1}e$

14. From the case, what is the half-life of technetium–99m?

15. Technicium-99m disintegrates to ${}^{99}_{43}Tc$ and a form of radiation that facilities the imaging as its distribution is recorded by a special camera. Complete the nuclear equation shown below and from that, identify the form of the radiation.

    ${}^{99m}_{43}Tc \rightarrow {}^{99}_{43}Tc + ?$ (radiation)

16. Why do you think that a radioisotope that emitted the radiation you identified (in Question 3) was chosen for cardiac imaging and not one that emitted either of the other two types (discussed in Questions 4 and 5).

17. Assuming that all the technicium-88m remains in the body and undergoes disintegration, how much (of each dose) would remain after 6h, 12h, 18h, 1 day, and 2 days? If 60% is lost (via urine and feces) by Day 2, how much would still be in the body after two days?

18. ${}^{99m}_{43}Tc$ disintegrated to ${}^{99}_{43}Tc$, which is also radioactive. However, the latter's half-life is about 211,000 years. Explain the basis for Dr. Owusu's statement "But don't worry, it's converted to a form that gives out negligible radioactivity."

19. Explain how administration of ${}^{99}_{43}Tc$ leads to identification of blocked blood vessels or poor perfusion of blood in particular area(s) of the heart.

20. After the test, Mr. Carleton was asked to keep hydrated. What would be the reason for such advice?

21. After the test, Mr. Carleton was asked to avoid being around babies and small children for the rest of the day. What would be the reason for that?

22. Mrs. Carleton brought Mr. Carleton for the nuclear scans and returned to take him home in an eight-seater SUV. What precautions can she take to minimize radiation exposure to her on the way home and for the rest of the day?

23. You have a relative who is scheduled for a nuclear stress test and is concerned about the risk of radioactivity from the test. In no more than 150 words, explain to them the potential risks versus the potential benefit of the procedure.