




Atypical Gunshot Injury Traversing the Neck with an Unexpected Nonlinear Bullet Trajectory: a Case Report and Review of the Literature

Yuuki Matsui¹ · Sena Iguchi¹ · Emiri Sato^{1,2} · Yoichiro Sato¹ · Ken Shindo³ · Michiko Ishida³ · Yutaka Saito³ · Kazuki Nakamura⁴ · Yu Kushima⁴ · Masao Nishiwaki⁴ · Yori-hisa Imanishi^{1,5} 

Accepted: 11 January 2021 / Published online: 29 January 2021

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Abstract

Gunshot injuries involving the head and neck region yield profound morbidity and mortality rates. Projectile-related factors comprising various physical and dynamic properties of a bullet, as well as tissue-related factors, determine the disruptive effects of projectiles on living tissues. We experienced an extremely unusual case of a gunshot injury to the neck, wherein the bullet transversely penetrated across the deep neck structures to the contralateral side of the shoulder without damaging any vital organs. A 51-year-old man presented with a gunshot wound to the neck from a point-blank range. A bullet entry hole was observed on the left side of the neck without an exit hole; however, the patient was conscious, vital signs were normal, and no active bleeding, cranial nerve palsy, or aero-digestive tract injury was found. Imaging tests revealed a bullet lying in front of the right humeral head, which was extracted by emergency surgery. The patient was uneventfully discharged. According to the localization of the damaged tissues and the positional relationship between the bullet's entrance and its destination, the bullet was estimated to have nonlinearly traversed the neck by traveling through the interstructural spaces associated with the least tissue resistance. Our experience strongly suggests the importance of realizing the unpredictable nature of a bullet trajectory in a body. An appropriate understanding of various ballistic factors and wounding mechanisms can be of great help in the adequate assessment and management of patients with gunshot injuries.

Keywords Bullet · Gunshot injury · Head and neck · Nonlinear trajectory · Projectile · Wound ballistics

This article is part of the Topical Collection on *Surgery*

✉ Yori-hisa Imanishi
yori-hisa@ja2.so-net.ne.jp; y-imanishi@iuhw.ac.jp

¹ Department of Otorhinolaryngology-Head and Neck Surgery, Kawasaki Municipal Kawasaki Hospital, Kawasaki, Japan

² Department of Otolaryngology, Tokyo Women's Medical University, Tokyo, Japan

³ Department of Emergency Medicine, Kawasaki Municipal Kawasaki Hospital, Kawasaki, Japan

⁴ Department of Orthopaedic Surgery, Kawasaki Municipal Kawasaki Hospital, Kawasaki, Japan

⁵ Department of Otorhinolaryngology-Head and Neck Surgery, International University of Health and Welfare School of Medicine, Narita Hospital, Narita, Japan

Introduction

Gunshot injuries involving the head and neck confer a high potential for profound morbidity and mortality rates by damaging vital neurovascular structures, including the central nervous system, carotid arteries, and jugular veins [1]. The main manners of firearm-related death comprise homicide, suicide, and accidental events, the rates of which largely vary depending on region and country [2]. In contrast to countries with gun-tolerant laws such as the USA, in Japan, even emergency physicians rarely treat patients with gunshot injuries because of their infrequency. In fact, the age-standardized mortality rate associated with firearm injury in Japan was estimated to be less than 0.2 per 100,000 persons in 2016, representing the second-lowest worldwide [2]. These low gun-related death rates are principally attributed to stringent Japanese laws that do not allow civilians to possess or use guns for any reason. Even with these laws, however, illegal distribution of firearms among domestic gangsters sometimes leads to gun-related

injuries in urban areas. Therefore, we need to provide gunshot wound victims with appropriate management supported by a relevant understanding of wound ballistics, even though it is relatively unfamiliar to and challenging for many surgeons.

Although a bullet is commonly thought to travel through the body in a straight line, a few patients with head and neck gunshot injuries who survived without lethal organ damage thanks to a nonlinear bullet trajectory have been reported [3–5]. However, there is no report of a patient who survived a gunshot wound transversely penetrating the entire neck across its deep structures. Here, we present an extremely unusual case of a gunshot injury traversing the neck, wherein the bullet nonlinearly traveled through the deep structures to the contralateral side of the shoulder without damaging any vital organs. We discuss the clinical implications of wound ballistics in gunshot injury to interpret the mechanisms underlying the unpredictable nonlinear bullet trajectory by analyzing the case from several different aspects.

Case Presentation

A 51-year-old man presented to the emergency outpatient room of Kawasaki Municipal Kawasaki Hospital because of gunshot wounds resulting from a local gang conflict in the vicinity. He was shot twice on the left side of the neck and face from point-blank range. On admission, he was conscious, and vital signs were within normal limits. He showed no signs of airway distress or pharyngeal injuries such as hematemesis or dysphagia. On physical examination, two bullet injuries were confirmed (Fig. 1). One injury was a bullet entry hole with minimal bleeding in the left lateral region of the neck, just below the level of the upper rim of the thyroid cartilage. There was no exit hole. Although the left neck was slightly swollen and tender, no active bleeding or subcutaneous emphysema was observed. The other bullet injury was a superficial lacerated wound, approximately 7 cm in length, in the left temporal region,

along with a perforating wound in the left auricular cartilage.

Transnasal endoscopy found mild edema confined to the left arytenoid region, whereas no bleeding, clots, or mucosal damage was observed. Functional disability was not found in laryngeal and pharyngeal motor function including phonation and swallowing. While no neurological deficit was noted in the cranial nerves, he had difficulty raising the right arm and flexing the elbow. A manual muscle test showed grade 0 in the right upper extremity, including the C5 region muscles, namely the supraspinatus, infraspinatus, subscapular, deltoid, and biceps brachii, indicating severe brachial plexus palsy. X-ray and computed tomography (CT) revealed a bullet lying on the anterior surface of the right humeral head, along with a comminuted fracture of the right clavicle (Fig. 2a, b). CT also displayed soft tissue edema and small air sacs among the deep tissue structures, including fat, muscles, fascia, and connective tissues, seemingly along the bullet path (Fig. 2c), whereas dynamic CT showed no evidence of active extravasation.

Because of a possible risk of infection relating to the bullet, we gave priority to removal of the bullet. Emergency surgery was performed using a C-arm (X-ray image intensifier) to enable exact localization of the bullet under general anesthesia. The bullet was identified inside the deltoid muscle (Fig. 3a) and extracted (Fig. 3b). The other wound on the left temporal region was simply sutured. He was put on a course of parenteral antibiotic treatment with cefazolin sodium (1 g) twice a day for 5 days, along with hydrocortisone (300 mg) daily; the latter was gradually tapered. A CT scan obtained 4 days after admission showed reduced neck edema and the disappearance of the air sacs. The postoperative period was uneventful, although no recovery from the right brachial plexopathy was observed. The patient was discharged 5 days after admission without any additional intervention. Because the patient did not return to the orthopedic outpatient clinic, possible improvement in his right brachial function remained unknown.



Fig. 1 Appearance of the two bullet wounds in the head and neck. **a** A bullet entry hole in the left lateral region of the neck. **b** The other bullet wound has lacerated the left temporal skin superficially and perforated the left auricular cartilage



Fig. 2 X-ray and CT images of the right shoulder and neck. **a** A-P view of X-ray revealing a bullet in front of the right humeral head (arrowhead) and a comminuted fracture of the right clavicle (arrow). **b** An axial CT

section demonstrating a bullet lying on the anterior surface of the right humeral head (arrowhead). **c** An axial CT section displaying edema and air sacs among the deep tissue structures

Discussion

The primary reason for mortality after penetrating neck trauma is uncontrollable hemorrhage due to major vascular injury [6, 7]. Because the head and neck region is densely occupied with vital structures in a relatively small volume, even the minimal motions of a penetrating bullet can simultaneously inflict severe damage to a major artery, vein, and nerve, leading to serious life-threatening conditions. This anatomical property is reflected in the high mortality rates associated with head and neck-related firearm injuries that reach up to 35–36% [8, 9]. Furthermore, in terms of the proportion, while the head and neck region accounts for only 13.8–20% of all gunshot injuries [8–10], deaths from head and neck-related firearm injuries account for as high as 54–58% of all firearm-related deaths [8, 9].

The effects of projectiles on living tissues, termed “wound ballistics,” are regulated by many factors, both projectile- and tissue-related [11, 12]. Ballistic factors consist of the physical properties of a bullet, including its mass, caliber, shape, and construction; the dynamic properties including bullet velocity, trajectory, pitch, and spin motion; the type and caliber of the barrel; and the distance traveled by the bullet [4, 11, 12]. Among these, the mass and velocity of the bullet are considered the most critical for determining tissue damage, because

they constitute kinetic energy (KE) as being equal to one-half the mass (m) times velocity (v) squared ($KE = 1/2mv^2$), which defines the maximum wounding potential [4, 11–13]. As a result, the faster a bullet is fired, the more KE is generated, increasing the potential tissue damage. Because the muzzle velocity of the bullet is defined by the length of the barrel and the explosive quantity [14], handguns with short barrel lengths generate lower velocity (less than 609.6 m/s), whereas rifles with longer barrel lengths produce a higher velocity (609.6 m/s or faster) [11–13]. As for our patient, because the assailant has not been arrested and the details of the incident under investigation are not allowed to be disclosed, neither the type of weapon nor the exact distance between the weapon and the body was officially confirmed. However, the patient testified that he witnessed the assailant fire bullets using a .38-caliber handgun from a very close distance, suggesting that his firearm injuries were presumably generated by a low-velocity shot.

Wounds generated by bullets are determined via their direct and indirect interactions with living tissues (Fig. 4) [4, 11, 14]. “Direct damage”, also called “prompt damage”, occurs with the rapid distension and rupture of tissue generated by the leading edge of the bullet passing through [4, 11]. This effect creates a “crush cavity”, also referred to as a “permanent

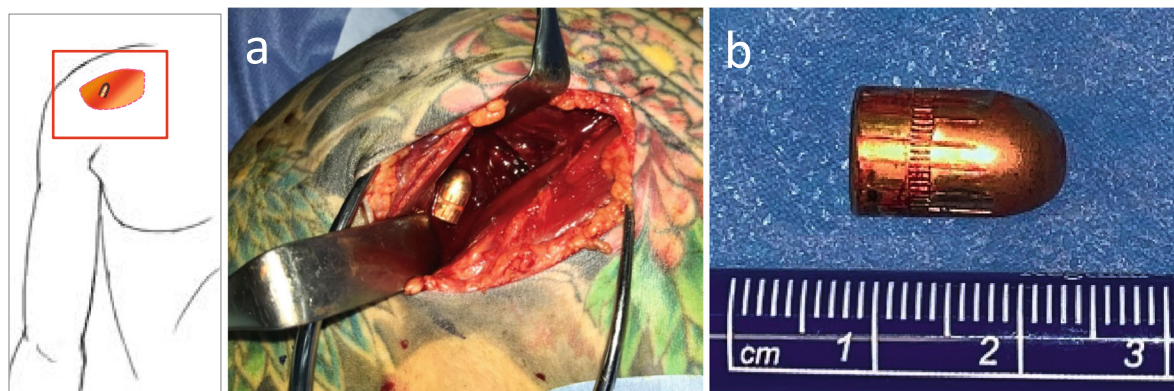


Fig. 3 Surgical view of bullet extraction. **a** The right deltoid muscle is opened, exposing the retained bullet. The red rectangle portion in the illustration indicates the photographed area. **b** The bullet retrieved from the body

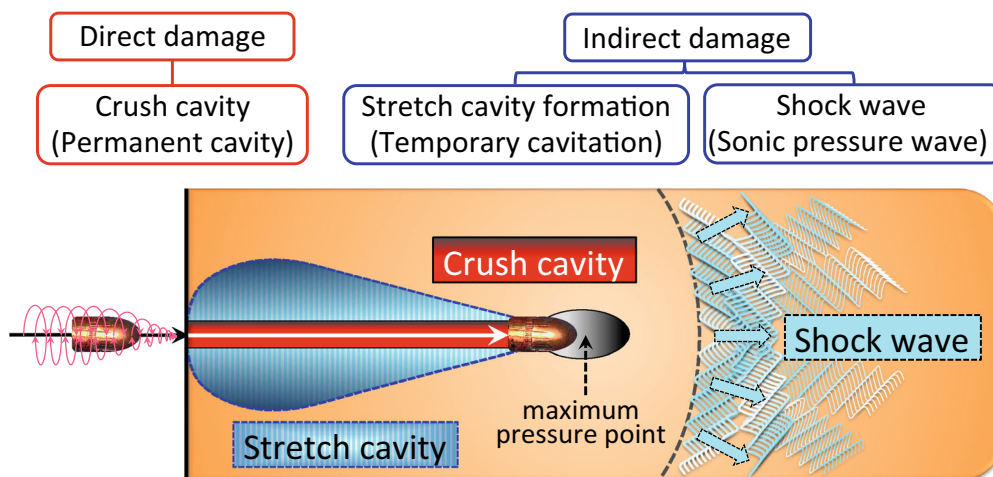


Fig. 4 A diagram illustrating the mechanisms underlying gunshot wounds. Direct damage occurs as a process of rapid distension followed by tissue rupture caused by the bullet passing through, with the formation of a crush cavity that corresponds to the central area of tissues disrupted along the projectile's track. Indirect damage develops via stretch cavity

formation and shock wave without direct contact between the tissue and bullet. The radial stretching of the tissue around the bullet tunnel creates a temporary cavity, indirectly injuring tissues in the surrounding area. The maximum pressure point at the leading edge of the bullet generates a stress wave that spreads ahead rapidly as it penetrates the body

cavity”, corresponding to the central area of tissues disrupted along the projectile's track [11–14]. On the other hand, “indirect damage” develops without direct contact between the tissue and projectile through a pair of highly dynamic pressure phenomena referred to as “stretch cavity formation” (also termed “temporary cavitation”) and “shock wave” (also called “sonic pressure wave”) [11–14]. Stretch refers to the radial stretching of the tissue around the bullet tunnel, which yields the surrounding area of indirectly injured tissues and creates negative pressure that may draw in foreign objects such as clothing material, sand, hair, and bacteria into the wound [12–14]. At the point of impact, a stress wave is generated and rapidly spreads ahead from the maximum pressure point at the leading edge of the bullet [11, 12, 14]. This shock wave penetrates through the body without actual tissue movement [11]. Bullets shot at a higher velocity cause more intense indirect damage by producing greater pressure changes [11, 14], requiring careful detection of latent damage to the surrounding tissues around the bullet's track [12]. Our patient seemed extremely fortunate to avoid injury to any vital organs in the neck, such as the carotid arteries, jugular veins, and upper aero-digestive tract including the pharynx, larynx, and trachea, even though the bullet had almost transversely passed through the neck structures to the contralateral side. Aside from minor crush injuries to the soft tissues along the bullet path, serious direct damage was seemingly limited to a comminuted fracture of the right clavicle and right brachial plexopathy. By contrast, indirect damage via stretch cavity formation and/or shock wave mechanisms was thought to correspond with a broad range of edema and air sacs found in the soft tissues around the bullet's track, with the former partly represented by mild mucosal edema in the left arytenoid.

The longitudinal axis of a fired bullet traveling “nose-on” tends to cyclically deviate from the tangent to its trajectory, a phenomenon known as “yawing”, and its complete turn beyond 90° is referred to as “tumbling” (Fig. 5) [11, 14, 15]. The destabilizing effect of yawing is counteracted by a high-frequency spin motion that provides gyroscopic stabilization, which maintains the bullet's “nose-on” orientation by decreasing the amplitude of yawing [11, 14]. This stabilizing spin force results in a complex spiral movement of the bullet's nose, called “precession”, wherein the bullet rotates around its center of mass located behind its mid-portion (Fig. 5) [11, 12, 14, 15]. Once the bullet enters the body, it cannot retain its preceding orientation because the stabilizing effect of the spin is overcome by tissue density far higher than that of air [11], which explains one of the reasons why a projectile does not necessarily follow a straight path when it passes through tissue. In addition, the unconstrained yawing or tumbling of the bullet allows its greater or entire length to act as its crushing edge, thereby maximizing the energy transfer [11, 12]. According to the X-ray image of our patient, the bullet lying on the right humeral head appeared to retain the “nose-on” orientation, which suggests that it did not tumble when penetrating the body, presumably due to a low-velocity impact.

The extent of tissue damage is also affected directly by deformation and fragmentation of the bullet, depending largely on the bullet design. Non-jacketed bullets, as well as semi-jacketed bullets (soft-point or hollow-point bullets) designed such that their tip is exposed from the jacket, can easily deform upon impact into a mushroom shape, thus transferring the KE more efficiently over a greater area of the target [11, 12, 14]. The abovementioned bullet designs are also aimed at causing fragmentation, in part or whole, upon impact. The resultant fragments, as well as any bone fragments generated

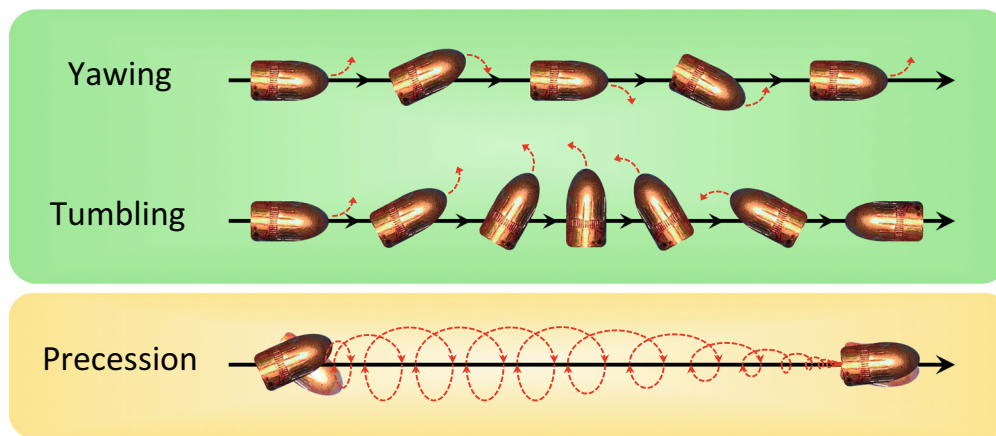


Fig. 5 A schema of the movements specific to a fired bullet. “Yawing” refers to the cyclical deviating movement along the longitudinal axis of a projectile from the tangent to its trajectory. Its complete turn beyond 90° is called “tumbling”. A high-frequency spin motion provides a

gyroscopic stabilizing effect to counteract yawing and maintain the bullet’s “nose-on” orientation, resulting in a complex spiral movement of the bullet’s nose, known as “precession”, wherein the bullet rotates around its center of mass

by the bullet, can act as individual secondary projectiles, thereby increasing wound severity [11, 12, 15]. In contrast, full metal-jacketed bullets are completely armored with copper and do not deform or fragment upon hitting a target, although they can penetrate the target easily [11, 12, 14]. Thus, awareness of bullet deformation and fragmentation helps us predict the degree of tissue damage. Concerning our patient, the bullet removed from the body was a full metal-jacketed bullet with neither deformation nor fragmentation (Fig. 3), as presumed by the X-ray and CT images (Fig. 2a, b), which also partly explained why the patient avoided lethal damage to the vital organs in the neck.

A bullet is generally believed to pass through the body in a straight line. However, the dynamics of a bullet can explain the possible nonlinear trajectories in a body. First, as

mentioned previously, when a bullet with yawing and precession enters the much denser living tissue, the loss of stabilizing spin motion amplifies its yawing and resultant tumbling, which makes the “nose-on” orientation unstable and helps the bullet deviate from a straight path [11]. Second, if the bullet hits bone, especially at lower velocity, it may deflect and turn direction, inevitably resulting in a twisted trajectory. Third, when passing through heterogeneous soft tissue structures, including artificial implanted materials, a bullet at lower velocity may be guided through a route of interstructural spaces where it encounters the least resistance [4], resulting in a curved or winding path.

The bullet trajectory was thought to be nonlinear in our patient according to the positional relationship between the bullet’s entrance and arrival point, as well as the localization

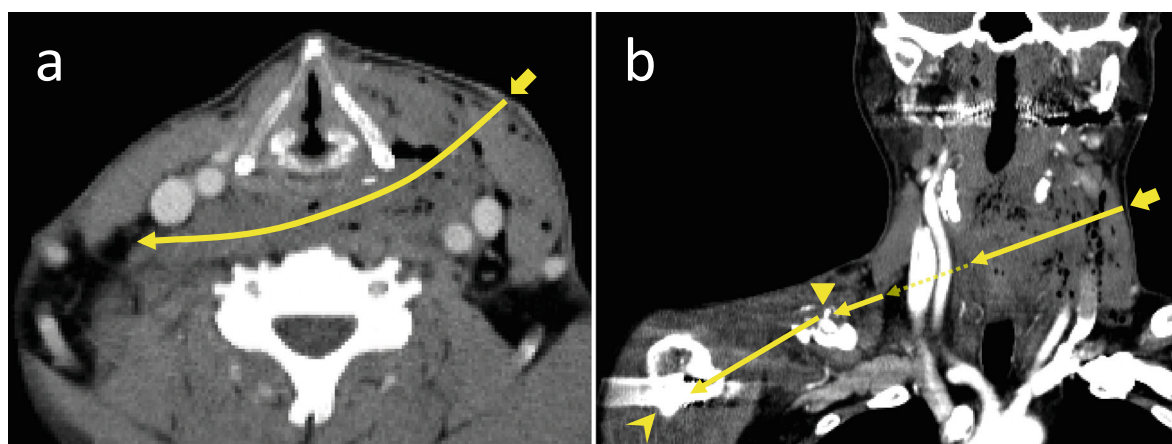


Fig. 6 Possible nonlinear bullet trajectory (long arrows) in our patient as estimated on CT images. **a** An axial section at the thyroid cartilage level. **b** A reconstructed coronal section, in which the plane has been rotated around a transverse (right-left) axis so that the bullet’s entrance and its final destination can be shown in nearly the same slice. The reconstruction was performed using AquariusNet Viewer V4.4.6.74 (TeraRecon

Inc.). After entering from the left side of the neck (short arrows), the bullet was assumed to pass between the thyroid cartilage and the common carotid artery, penetrate the retropharyngeal space diagonally downward by traveling in a curved line along the fascial planes, hit the right clavicle (triangle) and deflect inferolaterally, and finally land on the anterior surface of the right humeral head (arrowhead)

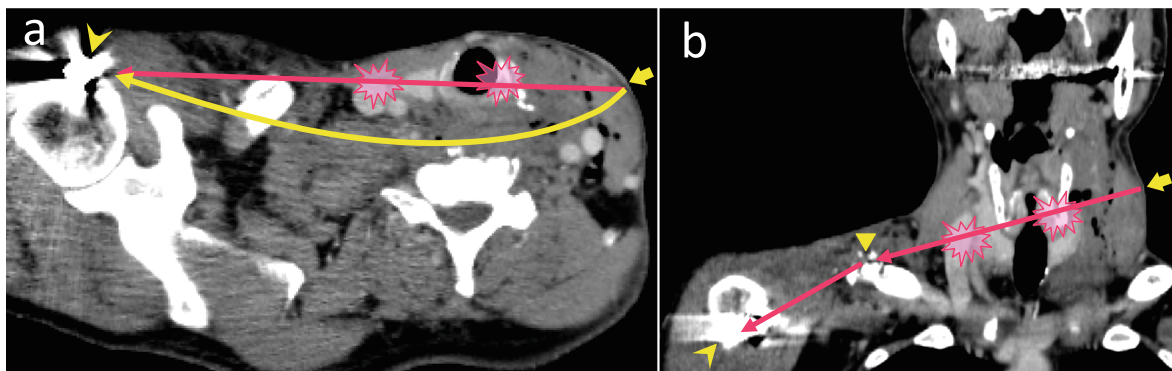


Fig. 7 A conceivable explanation for the nonlinear bullet trajectory (long yellow arrow) on CT images. **a** An axial section has been reconstructed by rotating the plane around an anteroposterior axis for visualization of the bullet's entrance and its final destination in exactly the same slice. **b** A coronal section has been further reconstructed by rotating the plane around a transverse (right-left) axis as well as a vertical (longitudinal) axis for the same purpose. If the bullet passed through in a straight line

from its entrance (short yellow arrows) to the destination (arrowheads: the bullet), the larynx and/or trachea, thyroid gland, and major blood vessels would be directly perforated (pink arrows with explosion icons). However, these organs remained unscathed. Instead, the bullet was estimated to travel through the interstructural spaces with the least resistance (long yellow arrow)

of soft tissue edema and air sacs in the deep tissue structures. The bullet's route was estimated as follows (Fig. 6). First hitting the left sternocleidomastoid muscle, the bullet passed through a very narrow gap between the thyroid cartilage and the left common carotid artery. Then, it penetrated the retropharyngeal space behind the hypopharynx diagonally downward from the left to the right, where it traveled in a curved line along the fascial planes and/or rebounded off the vertebral body. The bullet was assumed to pass behind the right carotid sheath, hit the right clavicle and deflect inferolaterally, and finally land on the front aspect of the right humeral head. If the bullet ran in a straight line to reach the aforementioned destination, the major blood vessels and the larynx and/or trachea would be directly perforated; however, they were unscathed in our case (Fig. 7). Instead, the bullet was thought to travel through the interstructural spaces, encountering the least resistance during its intrabody movement. Besides that, the effect of neck rotation at the time of injury, i.e., leftward rotation in this case, was suggested as another possible reason why the trajectory of the bullet appears nonlinear on CT. However, neck rotation would inevitably twist the pharyngo-larynx and cervical vertebrae in the same direction, thereby further narrowing the gaps between the pharyngo-larynx and the cervical vertebrae and between the pharyngo-larynx and the ipsilateral carotid sheath, which would make it even more difficult for a bullet to pass through these gaps without damaging these vital organs. Therefore, the possible effect of neck rotation on the nonlinear trajectory was considered to be minor.

To our knowledge, this is the first report of a patient who survived a gunshot injury wherein the bullet traversed the entire neck across its deep structures to the contralateral side of the shoulder, notably via a nonlinear path, traveling anterior to the left carotid sheath and posterior to the right carotid sheath without damaging any vital organs. Although various

patients with atypical head and neck gunshot injuries who survived without fatal organ damage have been reported [3–5, 16–22], those with a true nonlinear bullet trajectory are limited to only a few reports [3–5], where trajectories were implied to match the fascial planes with the least tissue resistance. Unlike our case, those reports suggested that the bullet penetrated the face from the masseteric region through the parapharyngeal and retropharyngeal spaces to the contralateral prestyloid space [4], or longitudinally passed through the unilateral side of the neck to the face from the caudal to the cranial side [3, 5]. Intriguingly, a couple of other case reports showed an unexpected route of a bullet that entered from the face, penetrated the facial cranium, passed through the nasopharynx, and ended up in the gastrointestinal tract by involuntary swallowing [17, 20]. Accordingly, our experience and these previous observations strongly suggest the importance of realizing the unpredictable nature of a bullet trajectory in a body, regardless of its entrance.

Conclusions

Taken together, an appropriate understanding of the wound ballistics can be of great help in anticipating the magnitude of tissue injury, detecting any latent damage to internal tissues, and estimating and interpreting the bullet trajectory, particularly in cases with an unexpected track, thereby enabling optimal management for victims of gunshot injuries.

Acknowledgements We would like to thank Editage (www.editage.com) for English language editing.

Author Contribution YM conceived of the study, managed the patient, collected and analyzed the data, and wrote the manuscript. SI, ES, and YoS helped manage the patient, participated in the data interpretation, and gave supportive advice. KS, MI, YuS, KN, YK, and MN managed the

patients and supported the data interpretation. YI provided comprehensive support to the study, helped interpret the data, and revised the manuscript. All authors read and approved the final manuscript.

Funding This work was supported in part by the Grants-in-Aid for Scientific Research (C) from The Japan Society for the Promotion of Science (16K11245 and 19K09876).

Data Availability The collected data that can identify the patient are not publicly available due to appropriate protection of patient privacy. All other data generated and analyzed during this study are included in this published article.

Declarations

Ethics Approval and Consent to Participate This report is a part of a comprehensive neck injury study, of which ethical approval was obtained from The Institutional Review Board and Research Ethics Committee of our hospital (#2017-20). Written informed consent for publication was obtained from the patient in this case report.

Conflict of Interest The authors declare that they have no conflict of interest.

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