Intraoperative Metal Detection vs. Preoperative computed tomography for Combat-related Shrapnel Localization: A Cadaveric Comparison

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ABSTRACT **Background:** Combat-related penetrating neck injuries (PNI) present distinct challenges in surgical settings. Accurate identification and removal of metallic fragments are crucial for minimizing complications. Although computed tomography (CT) remains the gold standard for preoperative assessment, use of intraoperative metal detectors may offer supplementary advantages by enhancing surgical accuracy and efficiency.

Objectives: To assess the technical feasibility of intraoperative metal detector assistance vs. a CT-guided primary approach.

Methods: Cadaver heads were implanted with metallic fragments from verified military-grade ordnance and subsequently underwent a CT scan. Two extraction approaches were evaluated: intraoperative metal detector assistance vs. CT-guided primary approach. Key metrics included incision length, dissection time, incision extension, and surgeon workload as assessed by the Surgery Task Load Index questionnaire.

Results: Metal detector-assisted extraction resulted in reduced initial incision lengths (3.50 cm vs. 4.87 cm) and smaller incision extensions (0.33 cm vs. 0.67 cm), indicating improved precision. However, the average dissection time was longer in the metal detector group (15:00 vs. 12:20 minutes), likely due to learning curves and additional scanning requirements. Surgeons reported lower situational stress (2.25 vs. 4.5) and reduced task complexity (4.0 vs. 4.5) when using a metal detector, despite noting increased mental demand associated with interpreting device signals during surgery.

Conclusions: Intraoperative metal detection technology shows significant potential as an adjunctive modality for shrapnel localization in combat-associated PNIs. It facilitates minimized incisions and improved surgical precision. While further optimization and clinical adaptation are necessary, this method holds promise for improving outcomes in both military and civilian trauma scenarios.

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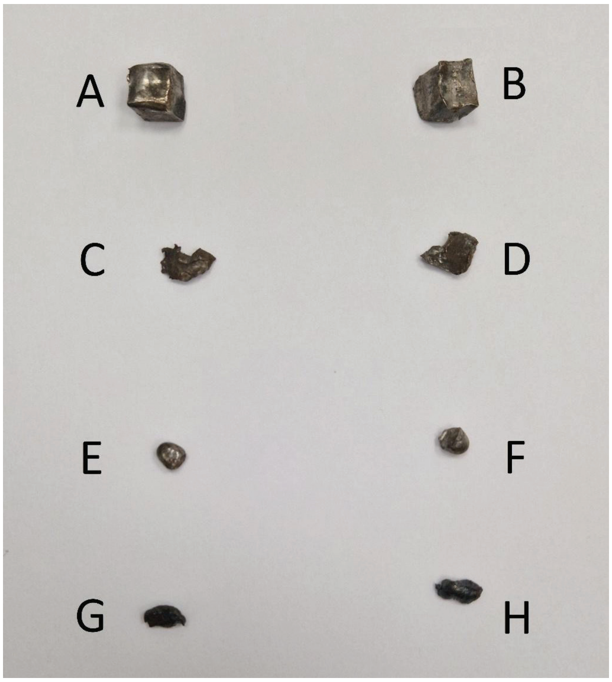
KEY WORDS: blast injury, combat trauma, metal detector, penetrating neck injuries, shrapnel

In modern warfare, penetrating injuries from bullets and shrapnel account for 90% of combat trauma among infantry personnel [1,2]. Extremities accompanied by primary soft tissue involvement are most affected (from 45% to 55%) [1,3]. Data from Iraq and Afghanistan showed that about 25–30% of combat injuries involve the head and neck, mainly due to explosive and shrapnel mechanisms [4]. Penetrating neck injuries (PNIs) in military settings differ markedly from civilian cases. Conservative treatment suffices for civilian PNI with stab wounds and low-velocity gunshot injuries [5,6] whereas combat-related trauma typically involves high-velocity fragments [7]. Despite these differences, substantial civilian populations face explosion and shrapnel risks from minefields, guerrilla warfare, terrorism, and conflicts.

While conservative management suffices for extremity foreign bodies [8], neck injuries present unique risks due to the proximity to critical vascular, aerodigestive, and neurological structures. Computed tomography (CT) angiography is the gold standard for PNI assessment in stable patients, consistent with the No-Zone approach, in which management is guided by hemodynamic stability and clinical/imaging findings rather than by the anatomical neck zone alone [9,10]. Surgical shrapnel extraction presents several challenges. Metallic foreign bodies produce beam-hardening and streak artifacts, which can distort their apparent size and shape and obscure adjacent structures, making it difficult to rely solely on CT imaging for precise intraoperative localization [11,12]. Theoretically, fragments may migrate between imaging and surgery due to patient movement or muscular activity. Last, fragments may be millimeters in diameter, and challenging to palpate intraoperatively. Current intraoperative modalities include ultrasonography and fluoroscopy. However, ultrasound is affected by acoustic

Figure 1. Real War-Zone Shrapnel

[A] Drone, head 1 Left, 7.60 mm × 10.0 mm × 7.45 mm,
[B] Drone, head 1 right, 7.90 mm × 9.90 mm × 7.0 mm,
[C] MON-50, head 2 left, 4.15 mm × 4.15 mm × 5.25 mm,
[D] MON-50, head 2 right, 5.0 mm × 5.0 mm × 4.75 mm,
[E] 40 mm, head 3 left, 4.90 mm × 3.35 mm × 8.10 mm,
[F] 40 mm, head 3 right, 4.75 mm × 9.10 mm × 3.50 mm,
[G] Grad, head 4 left, 3.0 mm × 11.10 mm × 6.90 mm,
[H] Grad, head 4 right, 3.90 mm × 8.20 mm × 11.35 mm



shadowing artifacts, while fluoroscopy disrupts surgical workflow. Previous research by Vesenjak and colleagues [13] demonstrated that combining a handheld metal detector with a navigation system can facilitate localization and removal of metallic shrapnel in a limb phantom model. This study compared metallic shrapnel extraction methods: intraoperative metal detector assistance versus a CT-guided primary approach. They used a human cadaver model and authentic war-zone fragments.

PATIENTS AND METHODS

This cadaveric study was reviewed by the institutional review process, which found no ethical objection to use of these donated heads for research. A waiver was granted in accordance with local requirements for research involving human remains.

Four frozen cadaver heads underwent a CT scan in a supine position for fragment implantation planning and then defrosted. The Explosive Ordnance Police Bomb Disposal Division supplied verified fragments from war zones, documented by size and weapon origin: military-grade drone, MON-50 Soviet anti-personnel mine, 40 mm anti-personnel round, and Soviet 122 mm Grad missile [Table 1, Figure 1]. A head and neck surgery resident (E.H.) made incisions far from the designated implantation sites near the mandibular ramus, inserting fragments bluntly. For each head, paired fragments of similar size and weapon origin were selected.

Table 1. Shrapnel characteristics, weapon of origin, and extraction surgery data

Head #	Study group	Shrapnel type*	Type	Size (mm)	Volume (mm^3)	Distance from surface (mm)	Distance from bone cortex (mm)	Time of dissection (min:sec)	First incision size (cm)	Final incision size (cm)	Incision extension Δ(cm)
1	**Metal detector**	A	Drone	7.60 × 10.00 × 7.45	566.2	42	8.95	16:00	3	4	1
	CT approach	B	Drone	7.90 × 9.90 × 7.00	547.47	25.4	11.8	05:10	7.5	7.5	0
2	**Metal detector**	C	MON-50	4.15 × 4.15 × 5.25	71.1	20	7.1	abort	4	abort	abort
	CT approach	D	MON-50	5.0 × 5.0 × 4.75	93.3	11.8	3.9	abort	4.5	abort	abort
3	**Metal detector**	E	40 mm	4.90 × 3.35 × 8.10	132.96	14.2	6.5	25:00	4	4	0
	CT approach	F	40 mm	4.75 × 9.10 × 3.50	151.29	11.9	3.7	22:00	3.5	5.5	2
4	**Metal detector**	G	Grad	3.00 × 11.10 × 6.90	229.77	11.8	3.1	04:00	3	3	0
	CT approach	H	Grad	3.90 × 8.20 × 11.35	362.97	12.9	3.8	09:50	4	4	0

*Shrapnel type is shown in Figure 1

CT = computed tomography

Incisions were closed with intradermal sutures to conceal insertion paths, preventing visual identification of insertion routes. Three cadaver heads had fragment pairs inserted from the temporal area, under the zygomatic arch, through the temporal fossa to mandibular ramus locations. One head had fragments inserted posterior to the sternocleidomastoid muscle, as fragments were too large for temporal fossa insertion. Cadaver heads underwent a second CT scanning (Force, Siemens, Erlangen, Germany; HR40 kernel at 90 kVp). Reconstructions were performed in axial, coronal, and sagittal planes. We obtained 1 mm and 3 mm fragments. Each fragment was measured for size, distance from the mandibular cortex, and distance from the skin surface [Table 1, Figure 2].

Figure 2. Insertion technique and example coronal computed tomography scan of cadaver number 4 with shrapnel H and G

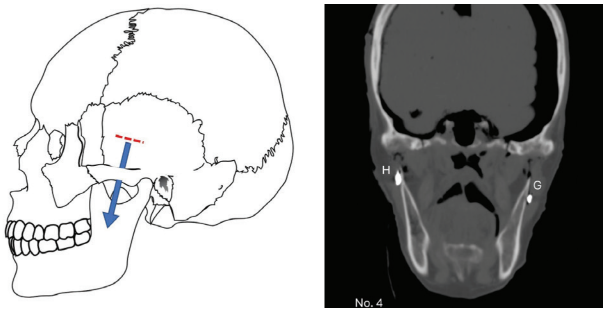
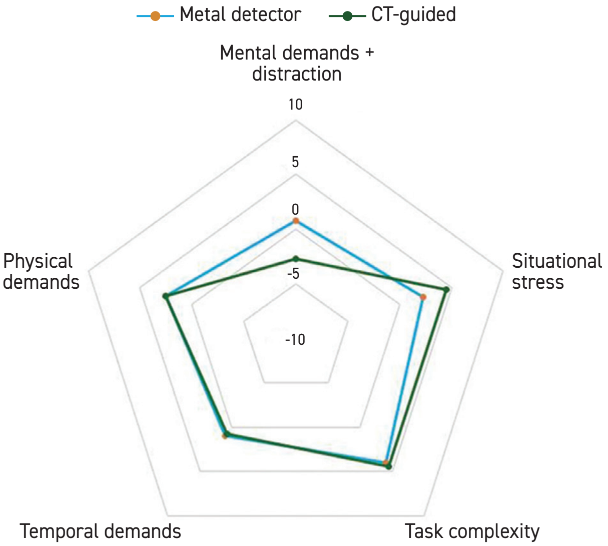


Figure 3. The SURG-TLX questionnaire was used to evaluate the perceived workload; mean SURG-TLX scores for the metal detector group vs. CT-guided only (-10) resemble the best possible score; (+10) resemble the worst possible score

CT = computed tomography, SURG-TLX = Surgery Task Load Index



The metal detector was recreational equipment (AV MINELAB PRO-FIND 40, Mawson Lakes, Australia), emitting increasing-frequency sounds when approaching metal and including manual sensitivity adjustments. A former military physician and experienced fellowship-trained head and neck surgeon (O.R.) performed all the procedures. For each matched fragment pair, one fragment was assigned by the investigator to CT-guided primary exploration and the contralateral fragment to metal detector-assisted exploration. No formal randomization sequence was used, and the surgeon did not choose the allocation.

FIRST APPROACH (CT-GUIDED PRIMARY APPROACH)

In the CT-guided primary approach, operative timing began after the CT review. The surgeon planned the incision according to standard surgical judgment (e.g., a modified Blair-type incision when appropriate). The dissection was performed to preserve the facial nerve and its branches. CT images could be reviewed as needed during the procedure. If progress was insufficient after 20 minutes, a metal detector could be used as a salvage option.

SECOND APPROACH (METAL DETECTOR-ASSISTED)

After a CT review, the surgeon used the metal detector to scan fragment areas, adjusting sensitivity and marking boundaries. Incision planning and dissection were similar to the first approach, but the metal detector provided orientation throughout. In both approaches, incision extension and CT review were options. The dissections were terminated after the fragments were located. The surgeon completed the Surgery Task Load Index (SURG-TLX) questionnaire to assess perceived workload and performance [14,15].

RESULTS

FRAGMENT LOCATION AND CHARACTERISTICS

The average fragment depth from the skin was deeper in the metal detector group (22.0 mm vs. 15.5 mm); mandibular cortex distance was similar (6.4 mm vs. 5.8 mm). Despite selecting similarly sized fragments, average volume was lower in the metal detector group (250.0 mm^3 vs. 288.7 mm^3) [Table 1].

OPERATIVE TIME AND INCISION CHARACTERISTICS

The average initial incision length was shorter with the metal detector (3.50 cm vs. 4.87 cm). Incision extensions were shorter with the metal detector (0.33 cm vs. 0.67 cm). The average dissection time was longer in the metal detector group (15:00 vs. 12:20).

SURG-TLX QUESTIONNAIRE SCORE ANALYSIS

Situational stress was reduced with the metal detector (2.25 vs. 4.5). Mental demand combined with distraction was higher with metal detector (0.75 vs. -2.75), probably due to the concurrent task loading as described by Wilson and colleagues [14]. Task complexity was lower with the metal detector (4.0 vs. 4.5). The average physical demands were identical for both approaches. The average temporal demands were worse with a metal detector (1.0 vs. 0.75) [Figure 3].

DISCUSSION

We compared CTguided shrapnel extraction with and without intraoperative metal detector assistance. The findings provide insights into metal detector use for combat-related PNI shrapnel extraction.

OPERATIVE EFFICIENCY AND PRECISION

Intraoperative metal detector use yielded reduced initial incision lengths (3.50 cm vs. 4.87 cm) and decreased incision extensions (0.33 cm vs. 0.67 cm) compared to CT-guided extraction, suggesting more precise localization and minimizing tissue manipulation. However, mean dissection time was longer with metal detector (15:00 vs. 12:20). This result may reflect a learning curve, scanning time, and salvage use example. In aborted cases, advanced tissue degeneration compromised anatomical integrity. Trial termination avoided bias and reflected realistic intraoperative judgment thresholds.

Cortical bone distance and shrapnel volume were measured to demonstrate no gross differences within cadaveric pairs [Table 1, and Figures A/B, C/D, E/F, G/H] regarding fragment size or mandibular depth, assuming no substantial variation in palpation ease or localization time.

SURGEON WORKLOAD

SURG-TLX results provide insight into surgeon experiences. The metal detector approach improved situational stress (2.25 vs. 4.5) and task complexity (4.0 vs. 4.5), suggesting a more structured, less stressful approach. However, increased mental demand and distraction scores (0.75 vs. -2.75) indicated additional cognitive resources required for signal interpretation. Wilson and co-authors [14] noted similar observations. In our study, a single surgeon found metal detectors particularly helpful for fragments changing location during dissection, whereas the CT-guided primary approach relied on palpation.

CLINICAL IMPLICATIONS

In combat-related PNI cases, precise shrapnel localization is essential. The neck's anatomy demands meticulous foreign body identification and removal. Metal detectors offer advantages including smaller incisions and enhanced accuracy, potentially improving outcomes in combat casualty care. CT remains the primary imaging method for stable PNI patients following the No-Zone approach and should not be abandoned. Metal detectors could be integrated as complementary tools. Unlike 2-dimensional imaging and ultrasound, metal detectors serve as additional instruments without workflow interference. They are intuitive with steep learning curves. For unstable patients unable to undergo CT before surgery, metal detectors could critically aid neck exploration. In selected pre-hospital or resource-limited settings, handheld detectors might also assist triage by suggesting whether a metal fragment likely penetrated soft tissue.

LIMITATIONS AND FUTURE DIRECTIONS

In this study, we used human cadaver models and real warzone shrapnel to simulate PNI. However, active bleeding absence should be considered when interpreting results. In addition, the detector used in this study was a recreational, non-medical device and was operated on cadaveric specimens only. Issues of sterile covering, compatibility with intraoperative monitoring, and integration into standard operating room workflows needs to be addressed in the design and evaluation of any future medical-grade instrument. Future research should focus on purpose-built medical metal detectors. Mean fragment volume was lower in the metal detector group, potentially reducing detection effectiveness. As an exploratory investigation, this study generated preliminary data and assessed technical feasibility rather than testing statistical hypotheses. Descriptive analysis provides foundation for subsequent hypothesis-driven research with appropriate statistical power. While intraoperative metal detectors show promise in improving surgical precision and reducing incision size, further research and refinement are needed.

In this exploratory cadaveric model, the findings support technical feasibility and suggest potential workflow advantages. Future work should focus on medical-grade device development and prospective evaluation in clinically relevant settings.

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Capsule

Single-cell transcriptomics reveals heterogeneity and immune microenvironment in lymphatic metastasis of head and neck squamous cell carcinoma

Lymph node metastasis is one of the strongest predictors of poor prognosis in head and neck squamous cell carcinoma (HNSCC). **Wei** et al. used single-cell transcriptomic analysis to investigate the cellular composition and immune microenvironment of lymphatic metastases. The study revealed marked heterogeneity among metastatic tumor cells, with multiple transcriptionally distinct subpopulations coexisting within metastatic lymph nodes. Some tumor-cell populations exhibited signatures associated with invasion, epithelial–mesenchymal transition (EMT), proliferation, and resistance to therapy. Analysis of the tumor microenvironment identified complex interactions between cancer cells and immune cells. Metastatic lesions contained diverse populations of T cells, macrophages, dendritic cells, and cancer-associated fibroblasts. Evidence of T-cell exhaustion and immunosuppressive macrophage activity suggested that metastatic tumors actively suppress antitumor immunity. Cell–cell communication analyses demonstrated extensive signaling networks that promote tumor growth, immune evasion, and metastatic progression. Several molecular pathways potentially amenable to therapeutic targeting were identified.

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