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# Forensic Characteristics of Injuries Sustained During the Explosion of Defensive Grenades

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## ABSTRACT

***BACKGROUND:*** The forensic examination of explosive injuries caused by fragmentation hand grenades is currently of particular interest because of high incidence and the lack of differential diagnostic criteria.

***AIM:*** To examine the morphological characteristics of injuries associated with the detonation of defensive fragmentation hand grenades F-1 and RGO.

***MATERIALS AND METHODS:*** The present study was conducted by visual assessments and measurements, along with observation, comparison, generalization, and systematization of the results obtained. Scanning electron microscopy and energy-dispersive X-ray spectroscopy were performed using a Hitachi FlexSem1000 II scanning electron microscope and a Bruker Quantax 80 energy-dispersive X-ray spectrometer for microstructural analysis.

***RESULTS:*** A detailed morphology of the explosive injury caused by the most commonly used defensive fragmentation hand grenades at varying distances was analyzed.

***CONCLUSIONS:*** The established morphological characteristics of the explosive injury caused by F-1 and RGO fragmentation hand grenades suggest that the type of grenade and the distance to the explosion epicenter can be reliably determined by the pattern of soot deposition, the number and morphology of tissue and biological object injuries. Scanning electron microscopy and energy-dispersive X-ray spectroscopy revealed the typical chemical composition of the damaging elements.

**Keywords:** explosive injury; fragmentation hand grenades; fragmentation injury.

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# Судебно-медицинская характеристика повреждений, полученных при взрыве оборонительных гранат

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## АННОТАЦИЯ

**Обоснование.** Изучение судебно-медицинских аспектов взрывной травмы, вызванной поражающими факторами при взрыве ручных осколочных гранат, в настоящее время представляет особый интерес в связи с большой частотой встречаемости и отсутствием дифференциально-диагностических критериев.

**Цель исследования** — изучить морфологические особенности повреждений, полученных при взрыве ручных осколочных гранат оборонительного типа Ф-1 и РГО.

**Материалы и методы.** Исследование проведено с использованием визуального и метрического методов, а также методик наблюдения, сравнения, обобщения и систематизации полученных данных. Для анализа микроструктуры объектов применены сканирующая электронная микроскопия и энергодисперсионный рентгеновский анализ, выполненные с помощью сканирующего электронного микроскопа Hitachi FlexSem1000 II и энергодисперсионного рентгеновского спектрометра Bruker Quantax 80.

**Результаты.** Проведён анализ морфологических особенностей повреждений, причинённых поражающими факторами при взрыве наиболее часто используемых оборонительных ручных осколочных гранат на различных расстояниях.

**Заключение.** Установленные морфологические особенности повреждений, причинённых поражающими факторами при взрыве ручных осколочных гранат Ф-1 и РГО, свидетельствуют, что по характеру отложения копоти, количеству и морфологии повреждений ткани и биологического объекта можно достаточно точно установить тип гранаты и расстояние до эпицентра взрыва. Сканирующая электронная микроскопия и энергодисперсионный анализ позволили выявить характерный химический состав поражающих элементов.

**Ключевые слова:** взрывная травма; ручные осколочные гранаты; осколочные повреждения.

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# 防御性手榴弹爆炸伤害的法医鉴定

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## 简介

**理由。**由于手榴弹爆炸造成伤害的因素导致的爆炸损伤的法医学研究目前因发生率很高，且缺乏鉴别诊断标准，具有很高需求。

**研究目的 。** 研究防御型F-1和RGO手榴弹爆炸损伤的形态特征。

**材料和方法。**这项研究通过视觉和度量方法，以及观察、比较、总结和系统化获得的数据的方法进行。为分析物体的微观结构，通过扫描电子显微镜 Hitachi FlexSem1000 II和能量扩散X射线谱仪Bruker Quantax 80进行扫描电子显微镜检查和能量扩散X射线分析。

**结果。**分析了最常用的防御破片型手榴弹在不同距离爆炸时的破坏因素造成的损伤形态特征。

**结论。**F-1和RGO手榴弹爆炸过程中破坏因素造成的损伤的既定形态特征表明，根据烟尘沉积的性质、组织和生物物体损伤的数量和形态，可以十分准确地确定手榴弹的类型和距爆炸震中的距离。扫描电子显微镜检查和能量色散分析揭示了破坏元素的特征化学成分。

**关键词：**爆炸伤；破片型手榴弹；弹片损伤。

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## BACKGROUND

The incidence of injuries caused by explosions of various explosive devices has been steadily increasing in recent years [1–3]. Consequently, explosive injury remains a pressing issue in forensic medicine. Currently, forensic pathologists have limited tools to differentiate the type of explosive device and determine the distance to the explosion epicenter based on the morphological characteristics of injuries on the victim's body and clothing. This underscores the need for further research and the development of differential diagnostic criteria for injuries resulting from the detonation of various types of grenades [4–6].

Fragmentation hand grenades remain the most commonly used explosive devices. They are categorized as:

- defensive
- offensive
- anti-tank.

Among defensive grenades, the most widely used are the F-1 (time-delay defensive hand grenade) and RGO (defensive fragmentation hand grenade).

The F-1 grenade has a cast-iron body shaped as an ellipsoid with a wall thickness of 4–9 mm and features three circumferential and eight longitudinal grooves. It contains 50–56 g of TNT as the explosive charge and is detonated using UZRGM[1] (UZRGM[2]) fuzes. According to current scientific sources, the explosion of this grenade produces approximately 1000 fragments weighing 0.1–1 g (with fragments over 0.8 g comprising about 4%). The fragments are irregularly shaped and disperse at a velocity of 700–800 m/s.

The total damage range is approximately 35–50 m, with an effective damage range of about 4–5 m [7].

The RGO grenade has a steel body with pre-formed fragmentation grooves. It is charged with approximately 90 g of TNT-RDX mixture and employs a UDZ[3] fuze. Upon detonation, the grenade produces 650–700 fragments weighing 0.4–0.45 g, dispersing at approximately 1200 m/s. The total damage range is 50–100 m, while the effective damage range is approximately 12–20 m [7].

## AIM

This work aimed to identify characteristic morphological features of injuries to clothing fabric and a biological human body simulator caused by the detonation of F-1 and RGO fragmentation hand grenades.

## METHODS

### Study Design

It was a single-center, cross-sectional, uncontrolled experimental study.

### Study Setting

Explosions of F-1 and RGO hand grenades were carried out in the field at a specialized testing range. The primed grenades were fixed in soil depressions and detonated remotely using a braided cord attached to the fuze ring. The biological target was a human body simulator, i.e. porcine forelegs with skin intact (no hair or thermal treatment), fixed to rigid particleboard substrates measuring 0.43 × 0.40 m. Each biological target was wrapped in white cotton fabric (calico) blended with up to 5% viscose, measuring 0.4 × 0.7 m. Explosions were performed at fixed distances: in contact, and at 20, 50, and 100 cm from the target, which was positioned 20 cm above the level of the explosive device. A total of 24 targets were examined (3 per each test series). Macroscopic and microscopic examinations were conducted using a Hitachi FlexSem 1000 II® scanning electron microscope (Hitachi HT, Japan) and a Bruker Quantax 80® energy-dispersive X-ray spectrometer (Bruker Physik AG, Germany). Scanning was performed in low-vacuum mode (VP-SEM 30 Pa) at magnifications ranging from ×45 to ×650. The accelerating voltage was 15 kV, the absorbed current was 600–800 pA, and the working distance was 12 mm. Spectra were acquired automatically until statistically reliable data (1 million counts) were obtained. Visual macroscopic analysis included morphological assessment of grenade fragments, determination of their elemental composition, and elemental mapping (chemical element distribution maps). Prior to scanning electron microscopy with energy-dispersive X-ray spectroscopy, large soft tissue residues were removed from the grenade fragments extracted from the biological target, followed by double degreasing in acetone.

### Ethics Approval

Ethics approval was not required as no laboratory animals were used in this study.

### Statistical Analysis

Sample size was not pre-calculated.

Statistical data analysis involved frequency assessment of identical diagnostic findings. Feature prevalence was calculated as the ratio of its frequency to the total number of observations within the group and equaled 1. Statistical

[1] Universal Modernized Hand Grenade Fuze (UZRGM) is a fuze model containing a slow-burning, low-gas pyrotechnic composition with high combustion stability, housed in an aluminum sleeve, and an azide detonator capsule enclosed in an aluminum casing.

[2] Universal Modernized Hand Grenade Fuze-2 (UZRGM-2) is a fuze model equipped with a less hygroscopic delay composition, featuring a combustion rate that is independent of ambient temperature.

[3] Impact-Time Fuze (UDZ) is a mechanical fuze designed for the detonation of fragmentation-blast hand grenades.

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processing of the elemental composition data of the fragments was performed automatically using the software of the Bruker Quantax 80® energy-dispersive X-ray spectrometer (Bruker Physik AG, Germany).

## RESULTS

A contact detonation of the F-1 grenade resulted in fragmentation of the biological and fabric targets, with fragments scattered within a radius of up to 14 meters. Some fragments were not found. Recovered fragments of cotton fabric with frayed edges measured between 2 × 1 cm and 30 × 25 cm, and some showed continuous black soot deposition. The biological fragments included soft tissue, bone fragments ranging from 0.7 × 0.5 cm to 5 × 3 cm, and soft tissue containing bone fragments. Some displayed continuous black soot coverage (Fig. 1, *a*).

At a detonation distance of 20 cm, the F-1 grenade caused uniform black soot deposition on both the fabric and biological target. The cotton fabric sustained numerous defects (35 ± 7), evenly distributed across the surface, ranging in shape from round to stellate, and in size from 0.1 × 0.1 cm to 1 × 0.7 cm. The defects had frayed, irregular edges with central fabric loss. The biological target exhibited multiple (⩾ 40) blind-ended injuries of round or oval shape, ranging from 0.1 × 0.1 cm to 0.7 × 0.5 cm, with peripheral black soot deposition. Fragments retrieved from the distal ends of wound tracks measured from 0.1 × 0.1 cm to 0.7 × 0.5 × 0.5 cm (Fig. 2, *a*).

At 50 cm, the F-1 grenade produced continuous dark gray soot deposition on the fabric and light gray soot on the biological target. Through-and-through injuries (17 ± 3) of the fabric target, mainly in the middle and lower thirds, were round, linear, stellate, or L-shaped, ranging in size from 0.1 × 0.2 cm to 6.5 × 1.5 cm, with frayed and mismatched edges. Multiple injuries in the biological target (⩾ 15–18) were primarily blind-ended (probability = 0.8) and, less frequently, tangential (probability = 0.2), oval or round in shape, measuring 0.2 × 0.3 cm to 5.5 × 4.5 cm. Soot deposition was noted on periphery and along the wound tract (Fig. 3, *a*). Fragments retrieved from the distal ends of wound tracks measured 0.2 × 0.2 × 0.1 cm to 0.5 × 0.4 × 0.3 cm.

At a distance of 100 cm, the F-1 grenade produced light gray soot deposition uniformly covered the target surfaces. Through-and-through injuries (5 ± 2) of the fabric, primarily in the middle and lower thirds, were round or oval with frayed, mismatched edges. Their dimensions ranged from 0.4 × 0.6 cm to 1.2 × 0.8 cm. Notably, the lower third of the fabric surface contained multiple (⩾ 5) irregularly rectangular dark gray metallic fragments, measuring from 0.1 × 0.1 cm to 0.2 × 0.3 × 0.1 cm. The biological target had 3–5 tangential or blind-ended injuries, oval or slit-like, measuring 0.3 × 0.3 cm to 2 × 1.5 cm. Retrieved fragments at the distal ends of the wound tracts ranged from 0.4 × 0.2 cm to 0.6 × 0.5 cm.

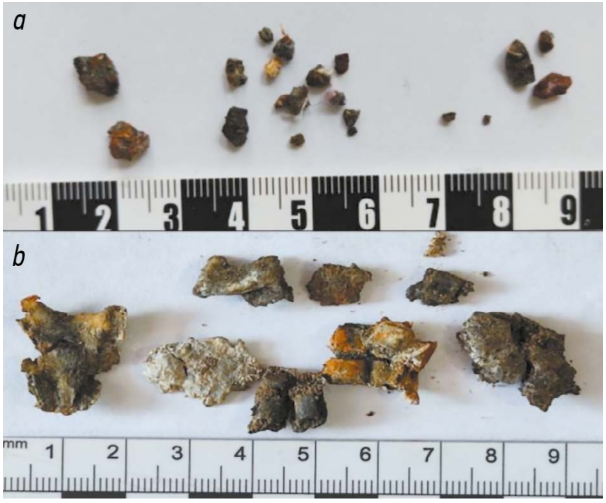


**Fig. 2.** View of fragments from F-1 and RGO grenades:
*a*, fragments extracted from a biological simulator of the human body after the explosion of F-1 grenade at a distance of 20 cm from the target;
*b*, fragments extracted from a biological target after the contact explosion of RGO grenade.

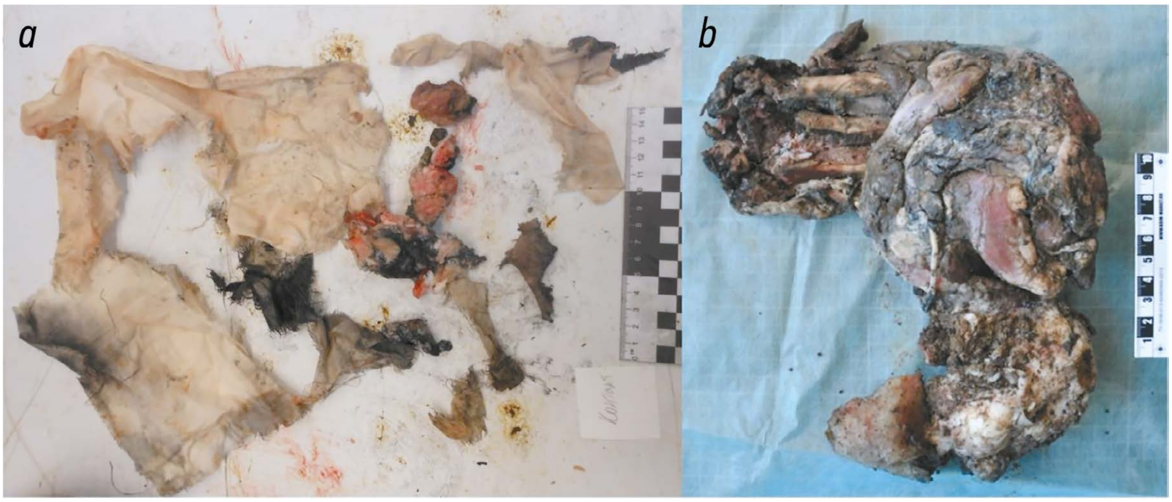


**Fig. 1.** A view of cotton fabric and fragments of a human body simulator during a contact explosion of F-1 (*a*) and RGO (*b*).

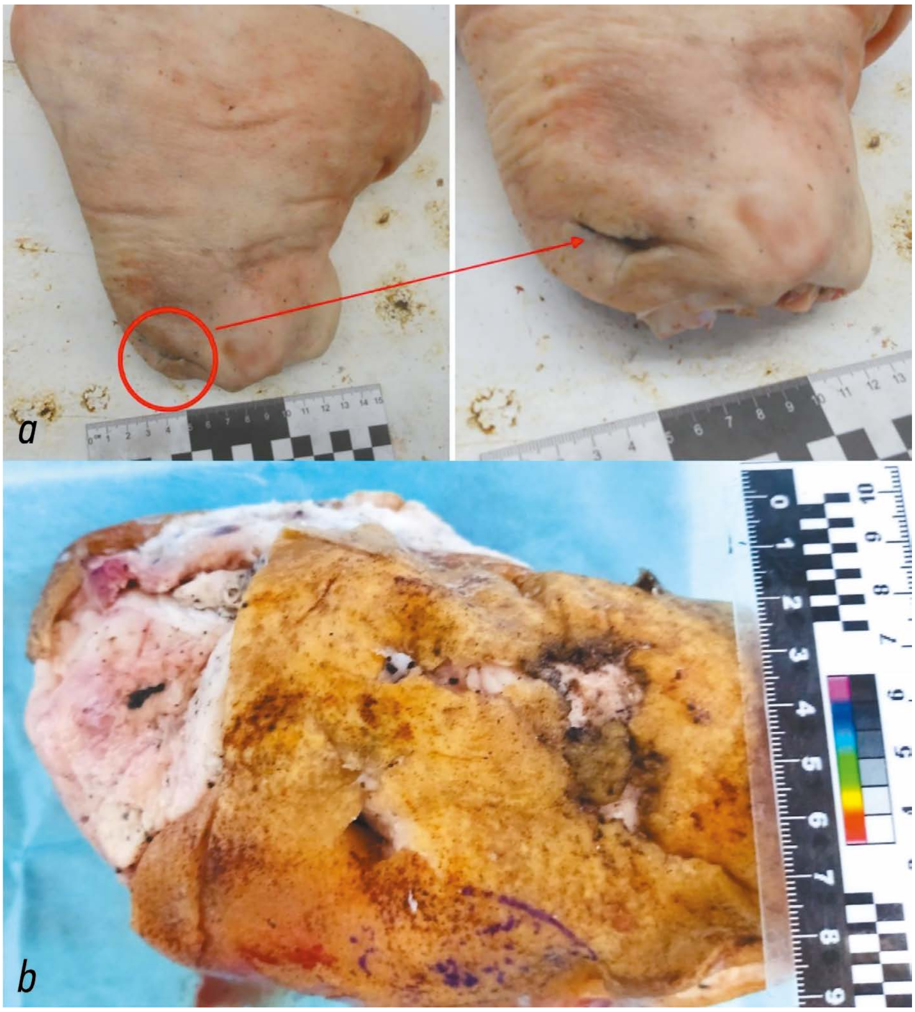

**Fig. 3.** A type of biological simulator of the human body: *a*, when an F-1 grenade explodes at a distance of 50 cm; *b*, when an RGO grenade explodes at a distance of 100 cm.

A contact detonation of the RGO grenade resulted in uniform black soot deposition on the fabric and biological targets. The fabric exhibited lacerated damage with frayed edges, with flap sizes ranging from 1.5 × 2.5 cm to 13 × 5 cm, and a prominent defect measuring 12 × 8 cm. The biological simulator revealed extensive injury with macerated, detached wound edges and a pronounced soft tissue defect. Complete oblique fractures of the bones without bone loss were also observed (see Fig. 1, *b*). Multiple rectangular metallic fragments measuring 0.5 × 0.5 × 0.1 cm to 2 × 1.5 × 0.1 cm were embedded in soft tissues (see Fig. 2, *b*).

At 20 cm, the RGO grenade caused continuous gray soot on the fabric and light gray soot on the biological target. Multiple through-and-through injuries of the tissue target (⩾ 40), evenly distributed, displayed various outlines—round, linear, or L-shaped. They measured 0.5 × 0.2 cm to 6.5 × 1.5 cm and showed mismatched edges. Frayed and severed fibres of varying lengths were present along the wound edges. The biological target sustained ⩾ 22 through-and-through injuries, slit-like or stellate, measuring 0.5 × 0.3 cm to 2.5 × 2.5 cm, with finely undulating mismatched wound edges.

At 50 and 100 cm, RGO grenade detonations produced no significant difference in soot deposition or wound morphology. Patchy pale gray soot was noted on the fabric, but was absent on the biological target. Isolated perforating injuries (1–3), mostly in the lower third of the fabric, were linear or L-shaped, measuring 0.5 × 0.3 cm to 3 × 1.6 cm, with matched edges with frayed and severed fibres of varying lengths. On the biological simulator, 1–3 injuries were slit-like or irregularly oval, mostly superficial blind-ended (probability = 0.8), and ranged from 0.5 × 0.3 cm to 3 × 2 cm. The wound edges were relatively smooth but mismatched (tissue defect), with peripheral gray soot deposition. Grenade metal shell fragments retrieved from the distal ends of wound tracks were quadrangular, 0.2 × 0.2 cm in size and 0.1 cm thick, and exhibited magnetic properties (see Fig. 3, *b*).

Scanning electron microscopy and energy-dispersive X-ray spectroscopy revealed characteristic surface features and elemental composition of the grenade fragments. F-1 fragments primarily contained iron and carbon with traces of aluminum, consistent with carbon steel. RGO fragments were composed mainly of iron with minor zinc content.

Differential diagnostic criteria for injuries caused by F-1 and RGO fragmentation hand grenades at varying distances, along with fragment characteristics and elemental composition, are summarized in Table 1.

**Table 1.** Differential diagnostic criteria for damage caused by damaging factors during the explosion of F-1 and RGO hand fragmentation grenades at various distances, fragments and their elemental composition

| F-1 Grenade | RGO Grenade |
|---|---|
| *Contact detonation* | |
| • Target fragmentation<br>• Fragments consist of soft tissues, bone splinters, and mixed soft-tissue/bone fragments<br>• Intense soot deposition | • Uniform black soot deposition across the entire surface<br>• Single extensive injury with macerated and detached wound edges<br>• Pronounced soft tissue defect<br>• Complete oblique-transverse bone fractures without loss of bone tissue |
| *Detonation at 20 cm* | |
| • Uniform, continuous soot deposition<br>• Multiple (⩾40) blind-ended injuries<br>• Round or oval shape with central tissue loss<br>• Injury dimensions: 0.1 × 0.1 to 0.7 × 0.5 cm<br>• Peripheral black soot deposition | • Uniform gray soot deposition<br>• Multiple (⩾22) through-and-through injuries<br>• Slit-like or stellate in shape<br>• Injury dimensions: 0.5 × 0.3 to 2.5 × 2.5 cm<br>• Finely undulating, mismatched wound edges |
| *Detonation at 50 cm* | |
| • Continuous dark gray soot deposition<br>• Multiple (⩾15–18) blind-ended or tangential injuries<br>• Round or oval shape<br>• Injury dimensions: 0.2 × 0.3 to 5.5 × 4.5 cm<br>• Black soot deposition on periphery and along the wound tracts | • Patchy pale gray soot deposition<br>• Isolated (1–3) superficial blind-ended or through-and-through injuries<br>• Slit-like or irregularly oval in shape<br>• Injury dimensions: 0.5 × 0.3 to 3 × 2 cm<br>• Relatively smooth but mismatched wound edges<br>• Gray soot deposition at the wound periphery |
| *Detonation at 100 cm* | |
| • Uniform light gray soot deposition<br>• Isolated (3–5) tangential or blind-ended injuries<br>• Oval or slit-like with central tissue defect<br>• Injury dimensions: 0.3 × 0.3 to 2 × 1.5 cm | • Injuries exhibited similar characteristics to those observed at 50 cm detonation distance |
| *Fragment characteristics* | |
| • Various geometric shapes<br>• Various sizes | • Predominantly quadrangular in shape<br>• Size: 0.5 cm |
| *Elemental composition of fragments* | |
| • Iron (Fe)<br>• Carbon (C)<br>• Aluminum (Al) | • Iron (Fe)<br>• Zinc (Zn) |

# DISCUSSION

This experimental study demonstrates that both the distance to the explosion epicenter and the type of explosive device can be determined based on the pattern of soot deposition and the morphological characteristics of damage to fabric and biological targets. These findings may be applied to forensic investigations of injuries sustained from the detonation of defensive fragmentation hand grenades (F-1 and RGO).

# CONCLUSION

This experimental study established the distinct features of soot deposition and the morphological characteristics of injuries to cotton fabric and a biological human body simulator caused by the detonation of F-1 and RGO defensive grenades. Scanning electron microscopy and energy-dispersive X-ray spectroscopy revealed the typical chemical composition of the grenade fragments.

# ADDITIONAL INFORMATION

**Authors' contribution:** V.A. Kuzmina: data collection, writing—original draft; writing—review & editing; S.V. Leonov: data collection, writing—review & editing; P.V. Pinchuk, A.A. Khalikov: writing—review & editing. Thereby, all authors provided approval of the version to be published and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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