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# Gabion structures and retaining walls design criteria

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**Abstract**

Retaining structures, which are utilized as a solution to meet the horizontal soil pressures between two different soil levels, have a very common usage area in geotechnical engineering. Gabions, which have found application with the developments in material production and coating technologies, are also applied as a type of retaining structure. Gabions, which are especially economical and environmentally friendly solutions, are engineering structures with many advantages. Gabion structures are built by placing these baskets in a specific order and these structures are used in many applications of civil engineering like retaining walls in highways, railways, erosion prevention, slope stability, stream bed improvement, shoreline survey, bridge approach, etc. In this study, gabion-type structures and their main application areas, advantages, design criteria, and comprehensive literature summary are given.

## 1. Introduction

The stability problem due to lateral soil loads between distinct soil levels is a widespread problem in civil engineering. Structures that connect these different soil levels by keeping them stable against the horizontal soil pressure created by static or dynamic loads are defined as retaining structures. Although there are a lot of types of retaining walls, gabion walls have been commonly begun to utilize in many applications of geotechnical engineering around the world. Gabion walls are preferable to stone retaining walls whose materials cannot be obtained easily, labor costs are high, and performance in the case of earthquakes is low. As the gabion has a cellular structure, these gaps fill with soil naturally over time. Also, it is possible to green gabion baskets artificially by adding bio textiles. Gabion structures are eco-environment friendly structures thanks to vegetation formation and are durable to environmental impact.

Gabion is originally an Italian word that means big cage. A gabion basket is a rectangular cage obtained from hexagonal double-twisted and zinc-coated steel wire mesh and filled with stone or rock of certain size and mechanical characteristics. Gabion structures are built by placing these baskets in a specific order and these structures are used in many applications of civil engineering like retaining walls in highways, railways, erosion prevention, slope stability, stream bed improvement, shoreline survey, bridge, or tunnel approach, etc. Gabion baskets adopted in composing the retaining wall have been seen as commonly utilized for different purposes according to historical ruins or structures from past to present. Gabions were primarily employed along the Nile River in 5000 BC in Egypt and along the Yellow River in China in 1000 BC, protection against coastal floods. Gabions were constructed as temporary walls for military purposes during Roman times and as a foundation for San Marco Castle designed by Leonardo Da Vinci. A gabion design was created by Egidio Palvis (1880–1929), one of the engineers of the Royal Union of Civil Engineers of Italy. The application of the gabion retaining wall, which is

accepted as the first engineering design, was made by the Maccaferri company in 1893, with sack gabions in the Reno River in Italy [1] (Figure 1).

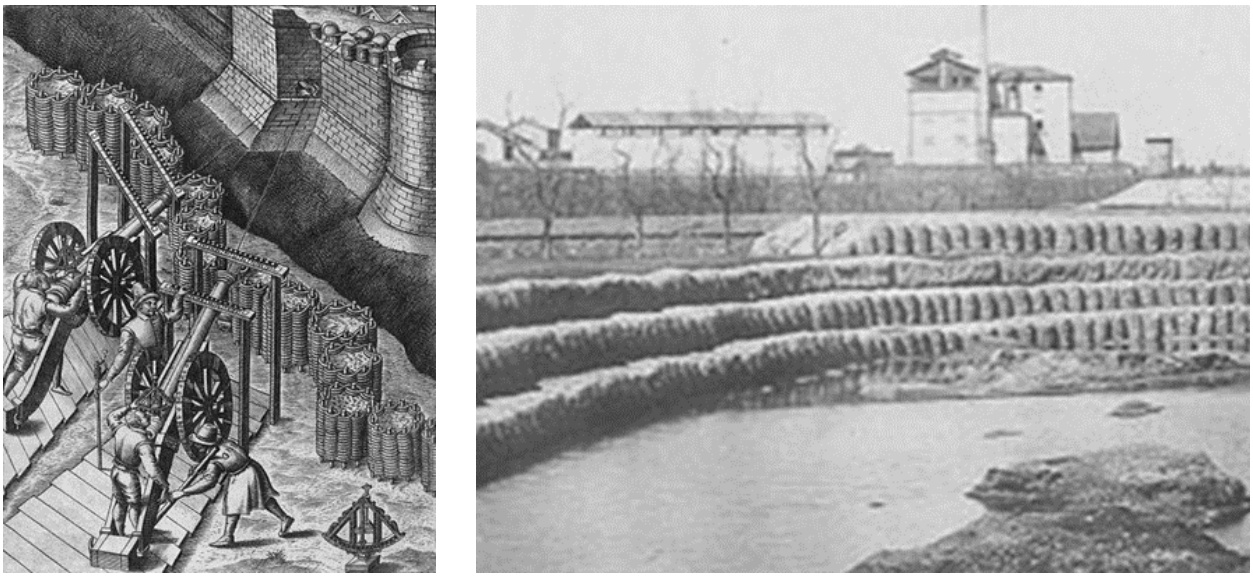

**Figure 1.** History of gabion structures [1]

Some of the analytical and experimental studies of gabion structures are tabulated as a literature review in Table 1.

**Table 1.** Literature review of gabion wall

| **Study** | **Explanation** |
|---|---|
| Flexible gabion structures in earth-retaining works [2] | The mechanical behavior of the gabion basket under the load and calculations of the gabion retaining wall were given in the study conducted by Agostini and Maccaferri which was thought of as the first experimental investigation. |
| Analytical study for the stability of gabion walls [3] | The effects of parameters such as wall height, wall inclination, the slope of backfill, and surcharge load on the stability of the gabion retaining wall were examined analytically for different values of the parameters. |
| The stability of gabion walls for earth-retaining structures [4] | The durability of the gabion wall against lateral loads, which is used effectively to prevent erosion in flood areas, was investigated experimentally in terms of gabion wall basket arrangement and gabion basket geometry change. |
| Settlement behavior of new reinforced earth retaining walls under loading-unloading cycles [5] | Elastic and plastic deformation for different types of reinforced soil structures under load was examined experimentally by exposing the loading-unloading cycle at different loading values. |
| Dynamic deformation behavior and life analysis of green reinforced gabion retaining wall [6] | Lateral and vertical deformation behaviors of green reinforced gabion retaining walls were investigated experimentally by imposing the dynamic loads with different frequencies and amplitudes to be able to estimate fatigue damage and fatigue life with train load and speed. |
| Multibody modeling of gabion beams for impact applications [7] | Shear and bending deformation for a multibody of gabion blocks which are likely to be used as a roadside impact absorption device were investigated experimentally and analytically. |
| Failures of gabion walls [8] | It is a review study which is presented failures and defects of gabion walls due to failure types like bulging, corrosion, stone erosion, backfill cracks, or erosion foundation soil obtained by observing walls in different sites. |
| Investigation of design criteria for the type of gabion walls [9] | The effect of parameters like the wall height, base length, angle of internal friction, wall angle, and backfill slope on the gabion retaining wall design was investigated analytically based on statistics. |
| Optimization of a slope-stabilization system combining gabion-faced geogrid-reinforced retaining wall with embedded piles [10] | A gabion-faced geogrid-reinforced retaining wall system has been applied for the protection of the road against slope stability and parametric studies of the height of the slope, the ratio of the embedded length of the pile to the thickness of the unstable soil layer, and the ratio of the spacing to the diameter of the pile have been performed for the optimum slope stabilization infrastructure. |
| Numerical modeling of gabion retaining wall under loading and unloading [11] | A real-scale gabion retaining wall with a 4.5m wall height was analyzed using the finite element method under the effect of water pressure in a loaded-unloaded case and its crest displacement was measured for comparing the experimental one. |

## 2. Material and Method

Today, the necessity of constructing new highways and railways for passenger, freight transportation, or individual use has come to the fore under the influence of the increasing population and developing technology. Structures such as tunnels, viaducts, and bridges are widely used in transportation, especially in covering large distances in a short time because it allows for crossing great mountains and wide valleys. To serve safely this kind of road structure, it should be designed according to the possible dangers on the route like landfall or rockfall. In this scope, retaining structures that resist the lateral soil loads which are occurred in different soil levels are widely used in applications of filling and splitting works, deep excavation, slope stability, approach fill of tunnels, bridges, viaduct foundations, etc. In Figure 2, some of the applications for retaining structures are demonstrated.

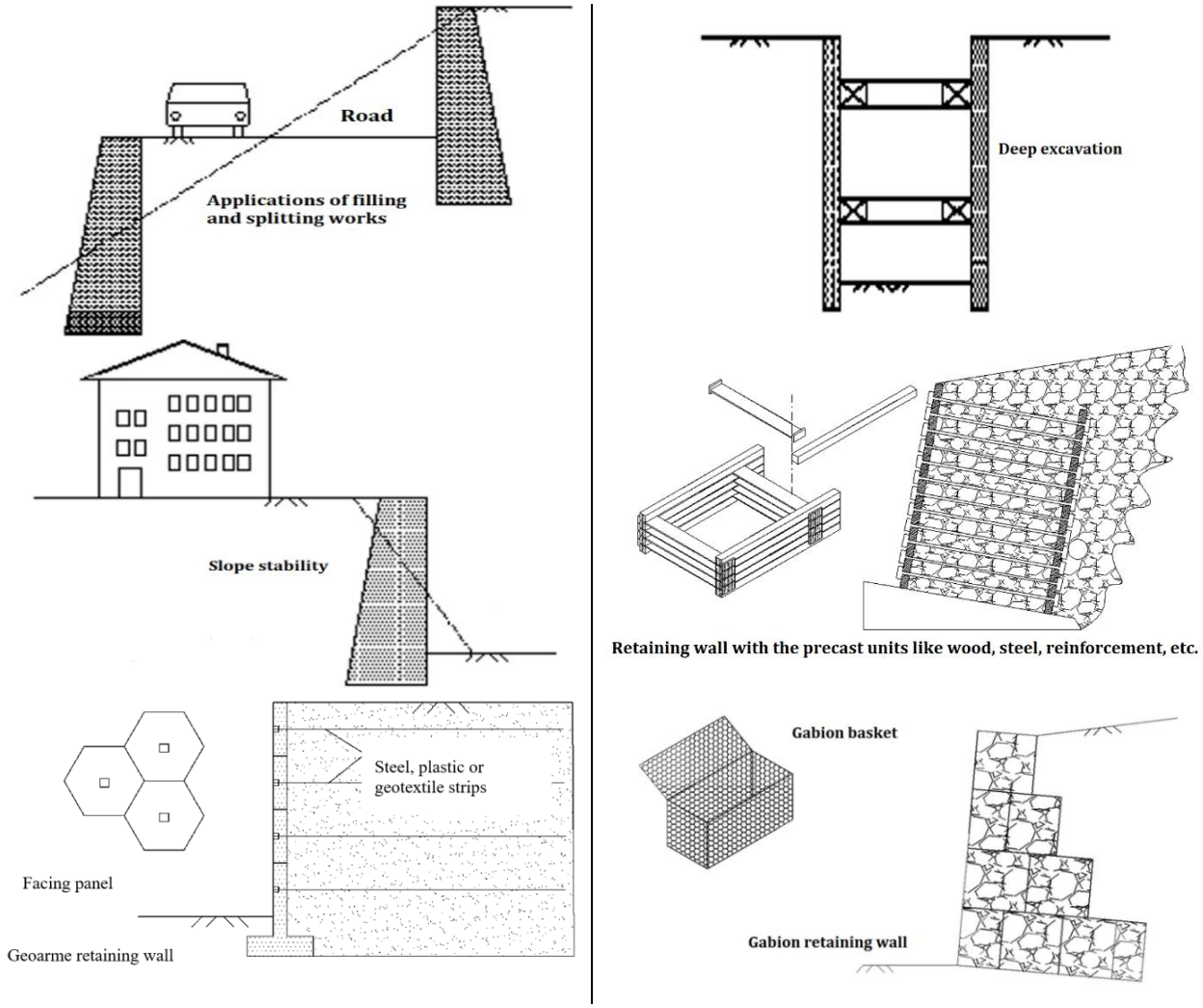


**Figure 2.** Retaining structures applications [12]

Gabion retaining walls which are retaining structures are an alternative and economic solution since they provide gabion basket filling material from the quarry or environment close to the site area and are a factory-produced material. Although it is possible to construct retaining walls as different types like stone, concrete, or reinforced concrete retaining wall, gabion retaining walls are more advantageous in terms of many criteria like flexible structure, economic, easily buildable, no needing drainage precaution, adaptive with the natural, durable, eco-friendly, and so on. Gabion retaining walls are favorable more than the other type of retaining walls (gravity) as the others require excess labor and manufacturing costs and periodical maintenance to prevent engorged. Also, tolerance of occurring failure due to a different settlement of soil is more acceptable for gabion retaining walls according to other retaining wall types. As gabion retaining walls are flexible in various settlements of the foundation soil and do not require an additional drainage system, thanks to their hollow structures, using these walls is advantageous compared to other retaining wall types. Gabion walls are economical as qualified workers are not necessary for assembling the gabion baskets packed and transported from the factory. Gabions are eco-friendly as allow the growth of vegetation and release less carbon dioxide into the atmosphere for transportation from the factory to the site and during construction, as well.

The comparison between a gabion retaining wall and other retaining walls like concrete or gravity retaining walls is tabulated in Table 2.

**Table 2.** Comparison of retaining walls [13]

| Comparison | Gabion retaining wall | Other retaining walls |
|---|---|---|
| Flexibility | flexible | rigid |
| Cellular structure | has | has not |
| Drainage precaution | is not necessary | is necessary |
| Employment cost | low | high |
| Time | can be constructed in a short time | takes a long time to construct |
| Settlement | adapts to different settlements | does not tolerate different settlements much |
| Environmental impact | suitable for vegetation growth | not compatible with the environment |
| Weight of the wall | light | heavy |

## 3. Applications of Gabion

Gabion baskets have been produced by using zinc-coated steel wire mesh covered with PVC, galvanic, galfan, polymer, etc., and double-twisted in various hexagonal aperture sizes (Figure 3). As the abovementioned cover of wire mesh provides resistance to environmental conditions, the gabion retaining wall has a long life like 30-100 years depending on covering materials compared with other types of retaining walls. Gabion baskets, which have a specific geometric form, are filled with small rocks and stones having suitable mechanical properties.

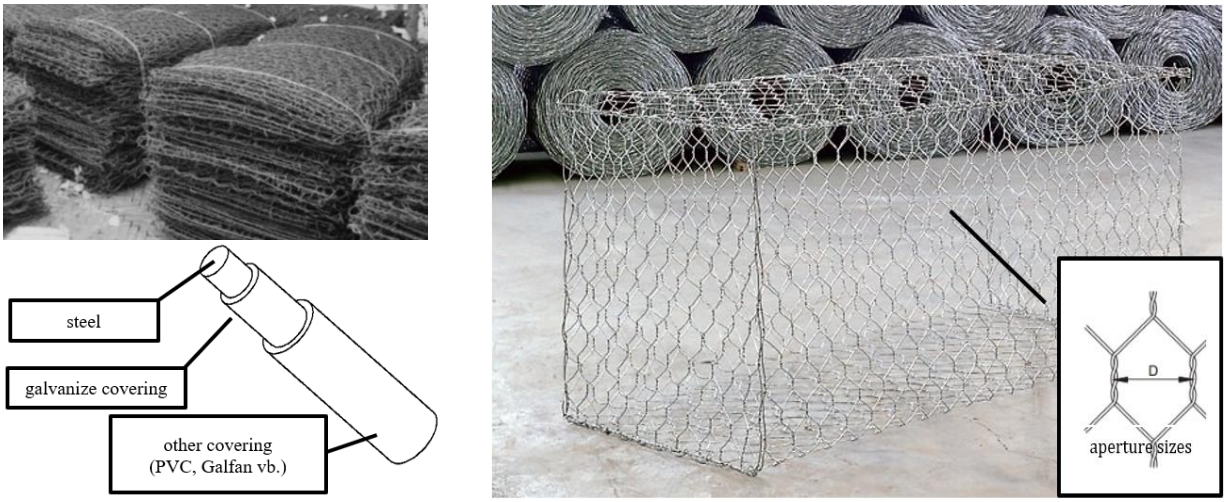


**Figure 3.** Gabion basket and wire mesh coating [12]

Gabion products like baskets, mattresses, sacks, or wire mesh have been commonly utilized in retaining walls, highways-railways, prevention of erosion, sediment transportation in rivers, falling rock or stone from slopes, remediation of a stream bed, shore protection as a breakwater, supporting of slopes, approach fill of tunnel and bridge and so on. Gabion products like baskets, mattresses, sacks, or wire mesh have been commonly utilized in retaining walls, highways-railways, prevention of erosion, sediment transportation in rivers, falling rock or stone from slopes, remediation of a stream bed, shore protection as a breakwater, supporting of slopes, approach fill of tunnel and bridge and so on. Gabion types like the basket, the mattress, the sack, and their different engineering applications are demonstrated in Figure 4.

The gabion structure which is widely used as a retaining wall is obtained by placing the gabion baskets of appropriate sizes in a certain order and connecting them to each other with suitable fasteners (Figure 4.a). Thus, soil which prone to lateral expansion is kept with a gabion retaining wall, and possible soil slipping problems solve on a natural or artificial slope near highways and railways. Gabion wire mesh is used to prevent the damage of large stones and rock fragments from natural slopes to the living creatures and structures in the vicinity. Since the wire mesh limits the movements of the rocks and ensures that the broken pieces are collected at the top of the slope, it creates a precaution against possible damages that may occur in the environment (Figure 4.b). The gabion mattress is an important and environmentally friendly alternative in the erosion solution to the desertification problem, which is encountered due to the movement of the soil mainly by the effects of rivers and seasonal precipitation (Figure 4.c). Gabion baskets are used in the bridge or tunnel approach to provide proper route in highways and railways (Figure 4.d). In contrast to reinforced concrete structures, mattress gabion is widely used in stream bed improvement. It is less damaged by hydraulic forces thanks to its flexible and hollow structure and is constructed quickly. In this way, it prevents the erosion and scouring of the riverbanks and ensures a smoother flow of the riverbed (Figure 4.e).

a

Embankment Manufacturing of Kozcağız Dam-Gabion Basket with Terramesh System [14]

b

Rock Barrier and Steel Grid Application of Kavşakbendi Project- Gabion Wire Mesh [15]

c

Application of Reno Mattress for Slope Erosion Prevention within the Scope of Ankara-Istanbul 2nd Stage High-Speed Train Project [16]

d

Construction of Terramesh System Retaining Wall within the Scope of Ankara-Istanbul 2nd Stage High-Speed Train Project [17]

e

Turkey, Astaldi Bolu Mountain Crossing Stream Bed Improvement Work for the Protection of Viaduct Foundations with Gabion Basket Reno Mattress [18]

**Figure 4.** Type of gabion products and some applications

## 4. Design Criteria

When the retaining wall with the gabion retaining wall are compared, it is commented that the gabion retaining wall is more flexible and is more reliable with its performance on different settlements and against earthquake loads. In design of gabion retaining wall design criteria is differ from conventional retaining wall. The design criteria of the gabion retaining wall have been presented as the following [12];

**Stability check:** In the design of the gabion retaining wall, it is necessary to inspect the structure in terms of stability problems caused by lateral soil pressure and perform a check of safety factors of sliding, overturning, bearing capacity, and slope stability according to proper safety factor limits in literature [19]. The active horizontal soil pressure coefficients according to Rankine [20] or Coulomb [21] theory etc. that are effective in the design are determined.

**Backfill material:** Due to the permeability of the gabion retaining wall, soil type is used in a wider area as filling material. While clayey soils that swell with water are not preferred as the backfill of the other type of retaining wall due to no possibility of draining the water in the reinforced concrete retaining wall, it is not a problem for backfill of the gabion retaining wall. Backfill soil is selected by evaluating factors such as the proximity of the place where the gabion retaining wall will be built to the quarries, the groundwater situation, and the excavation area.

**Foundation soil:** After the examination of the ground on which the gabion retaining wall will be built, the engineer designing the foundation should consider criteria such as soil bearing capacity, wall dimensions, drainage condition and ground settlement condition. During the preparation of the foundation, the upper ground is excavated until the solid load-bearing ground is reached and the foundation is formed with granular stone material in layers of 15-45 cm to increase the bearing capacity and reduce different settlements. Depending on the condition of the soil and the construction area, in some cases, the foundation is prepared by compressing the filling material with a compression ratio of 95%.

**Backfill soil:** By compression of the backfill soil placed behind the gabion retaining wall, the sliding resistance of the soil increases, the swelling-shrinkage behavior is controlled, the compressibility decreases, and the liquefaction problem is brought under control. In terms of the long-term performance of the gabion retaining wall, the filling material of the backfill soil should have a compression ratio of 95% on the condition that it is placed and compacted following local standards. Uncompacted or poorly compacted weak backfill soil may cause horizontal wall movement, structural settlement, and insufficient shear strength, reducing wall performance.

**Filling material of gabion basket:** Due to the permeability of the gabion retaining wall, soil type is used in a wider range for filling material of the gabion basket. Appropriate filling soil type should be placed and compacted by considering factors such as the proximity of the place where the gabion retaining wall will be built to the quarries, the groundwater situation, and the excavation area. The gabion fills in the hollow structure placed in the gabion basket provides free drainage to the ground behind the wall (Figure 5).

**Filter fabric:** The gabion retaining wall built without filter fabric placement is dragged on by the effect of free drainage, causing the loss of the soil and a decrease in the soil height. Therefore, filter fabric should be used to prevent soil loss (Figure 5).

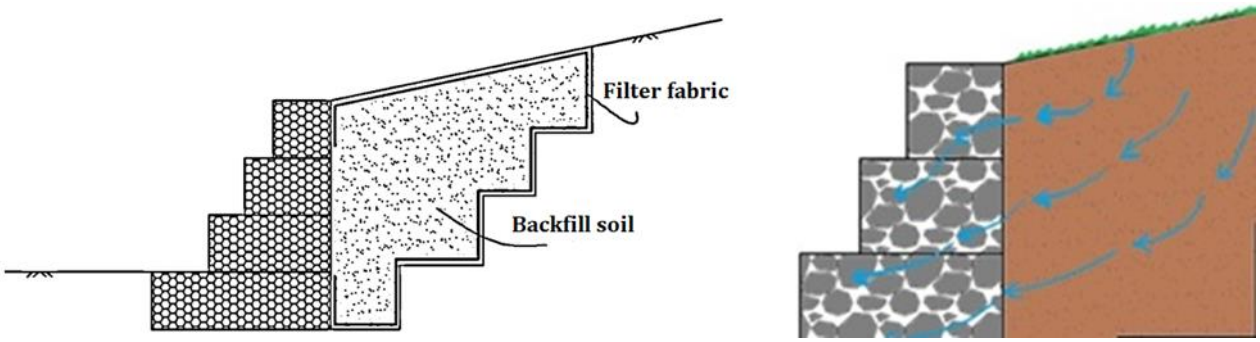


**Figure 5.** Application of filter fabric and permeability of gabion retaining wall [12-13]

## 5. Conclusion

In this study, the application case, advantages, and design criteria of the gabion structures have been presented with literature studies. Gabion structures are solutions for the problems meeting in many areas of civil engineering that provide safe, economical, and environmentally friendly. It is thought that the design and construction of gabion retaining walls without requiring any drainage measures, especially in soil environments where the groundwater level changes with the seasonal effect, will be a solution to the problem of demolition of retaining walls. Demolition of retaining wall may be due to the blocking of barbacane which is used for draining the water in time when the water accumulated if essential maintenance of the barbacane does not conduct.

The design criteria of gabion structures, whose use is becoming more and more widespread today, have not been fully developed. The design criteria and software utilized in the current situation are largely based on the experimental and analytical results obtained by the research and development studies of the manufacturers and the efforts of some researchers. Comprehensive finite element-based analyzes and experimental studies are required to fully develop the design criteria of gabion retaining walls, which are distinguished from stone, concrete, or reinforced concrete retaining walls with different properties like their porous structure and water permeability.

Consequently, the route can serve safely with reliable and effective gabion applications such as slope support, protection against rock or stone falls, tunnel approach filling in highways and railways. In addition, it is possible to make gabion structures that serve for many years due to their low cost and environmentally friendly solution.

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**Conflicts of interest:**

The authors declare no conflicts of interest.

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