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# Preliminary Study of the Spring-back/Spring-go Phenomenon in the V-Bending Process Using SGCC Steel Thin Material

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***ABSTRACT***

*This research analyses v-bending results using galvanized SGCC (JIS G 3302) sheet steel. The accuracy of the angle and dimensions of the bending results are the significant elements of the bending process that must be achieved. The bending spring-back/spring-go phenomenon has an impact on bending angle accuracy. If proper parameters are chosen, the spring-tub/spring-go angle should be minimized. This study aimed to see how the proposed v-bending process affected the spring-tub/spring-go angle value. An experimental approach was selected in this study. V-die bending opening, V-die punch angle, V-die punch speed, and bending force are all input parameters for the v-bending process. Meanwhile, in this study, galvanized steel with a thickness of 1.2 mm was used. The results of the ANOVA evaluation showed that the v-die punch speed and bending force are two parameters that affect the response of the variable, with a percentage contribution of 31.0% each. The minimum spring-back angle was found in the second sample, while the minimum spring-go angle was found in the fourth sample.*

***Keywords:*** *ANOVA; Exsperimental method; Spring-back/spring-go; V-bending; V-die punch*

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## 1. INTRODUCTIONS

Galvanized steel material is a material that has been widely used in recent years in the automotive industry [1], where this material has a good level of corrosion resistance [2]. These advantages have increased the use of galvanized materials by up to 70% [3]. Zinc coating on galvanized steel has its own challenges during the v-bending process. The selection of the right parameters helps to make it easier to obtain information on the occurrence of defects on the zinc surface during the v-bending process on galvanized steel material. The v-bending process is a metal-forming technique that is applied in various manufacturing industries [4]. Some parameters of the bending process that need to be considered include v-bending radius, material thickness, punch angle, holding time, die-punch speed, material temperature and rolling direction [5]. These bending parameters must be controlled because they will affect the results of the expected bending angle and dimensions. The results of the angles and dimensions of the workpiece are a number of output variables that must be achieved in all bending processes.

In recent years, research on bending has increased. Research on the topic of bending was carried out in order to find out the phenomena that occur in the bending process, especially related to the accuracy of corner bending [6] [7] [8]. Thipprakmas et al., have investigated the phenomenon of the bending process in the application of Al100-0 material. The research was conducted using the Taguchi experimental method. The v-bending angle, material thickness and die-punch radius are selected as variable inputs. The results showed that material thickness is the input parameter that most influences the input variable, followed by die-punch radius and v-die bending angle. In contrast to the spring-go phenomenon, the v-die bending angle is the most significant input parameter, which follows the material thickness and die-punch radius. Badr et al. [9] studied the spring-back effect of Ti-6Al-4V alloy in roll forming and v-bending processes. The results showed that there was little spring back in roll forming when compared to v-bending, [6] spring back/spring go investigations in v-bending simulations for A1100 type materials using material thickness, punch radius and v-die bending angles using optimization methods such as Taguchi. Based on reports submitted that material thickness and bending angle play an important role in reducing spring-back and spring-go followed by material thickness. [10] In conducting finite element analysis using AL2024-T3 to estimate the return spring in v-bending by providing variations in punch radius, die lip radius and punch angle. The conclusion obtained is that the spring decreases with an increase in the hitting radius and impact angle. [11] by considering the effect of grain size, punch radius, and die-punch speed on a pure iron plate in the micro v-die process. The results of this study can be concluded that the spring-back value decreases when the punch speed increases for small grain sizes, and the negative spring decreases with lower die-punch speeds for larger grain sizes. Then Ibrahim Karaagac [12] studied v-bending using flex forming in conventional processes using copper and brass sheets. The parameters used are holding time, bending angle and different pressures. Based on this application, it can be interpreted that surface defects are neglected in flex forming when compared to conventional methods. Fuzzy logic was used to evaluate the spring, and found that it was very similar to the experimental results. Montgomery comprehensively describes various methods for optimization, process parameters and their applications according to requirements [13]. Further research on the spring-back/spring-go phenomenon was carried out using 0.8 mm galvanized material [5] with the result that the die-punch angle is a parameter that has a high impact on the response variable. The contribution value is more than 75%.

In contrast to previous studies, the v-bending process research used SGCC galvanized steel material (JIS G 3302) with a thickness of 1.2 mm. As in the previous addition, the use of G 3302 galvanized steel, especially 1.2 mm thick, has not yet been implemented. The objective of this study was to analyze the response of the bending parameter to the spring-back/spring-go angle and the spring-back factor of 1.2 mm SGCC galvanized steel material. The implementation of this activity uses an experimental approach method with 6 (six) experimental examples.

## 2. METHODOLOGY

### 2.1. *Materials and test specimens*

In this study, SGCC galvanized steel material (JIS G 3302) was utilized. The SGCC steel grade is an easy-to-form hot-dip galvanized steel. JIS G 3302 specifies SGCC as the grade and designation for a particular type of material. The JIS G 3302 Japanese Industrial Standard applies to galvanized-in-place materials. Galvanizing a coil of SPCC cold rolled material produces hot dip galvanized steel of commercial quality. Zinc coating thickness is controlled by both width and thickness and is specified by JIS G 3302. Galvanized steel JIS G 3302 is an alloy of SPCC-SD steel (JIS 3141) zinc-coated JIS G3302 [14]. SPCC-SD material is a low-carbon steel material widely applied in the industry [15]. The mechanical properties and chemical composition of the SGCC JIS G 3302 galvanized steel material are presented in **Table 1**, where the zinc coating protects the steel surface from corrosion. The geometry of the SGCC thin plate material is provided in **Figure 1**.

**Table 1.** Mechanical properties and chemical composition (%) of SGCC steel

| Element | JIS G 3302 | CTQ1690A* |
|---|---|---|
| C | 0,15 max | 0,0494 |
| Mn | 0,08 max | 0,1830 |
| P | 0,05 max | 0,0080 |
| S | 0,05 max | 0,0044 |

| Parameter | JIS G3302 | CTQ1690A* |
|---|---|---|
| YP (N/mm$^2$) | 205 min. | 246 |
| TS (N/mm$^2$) | 270 min. | 355 |
| EL (%) | -. | 43 |
| Coating mass | Z18 | Z18 |

*. *Mild Certificate (CoA)*

The bevel protractor with an accuracy of 5 minutes (0.0833°) was chosen to measure the results of the v-bending process. Furthermore, all data is converted into units of degrees, where 1 minute = 1/60 degrees.

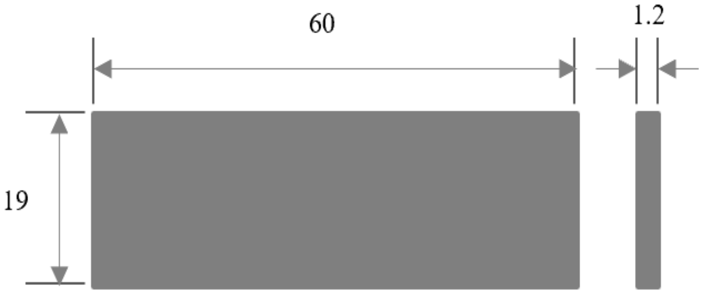



**Figure 1.** The geometric shape of the sample being tested

## 2.2. *Bending test*

The v-die bending test was applied to the Shimadzu Universal Testing Machine (UTM) AGS-X 10kN STD E200V with a capacity of 10 kN. The v-die bending test determines the magnitude of the spring-back/spring-go (SB/SG) angle and spring-back factor. The bending test was carried out with v-bending molds, which were processed using SKD-11 JIS G4404 material. For details on the materials used, see the JIS G4404 standard for alloy tool steels [15]. A specialized wire-cut electrode discharge machine is used in mold-making (WC-EDM). There are two types of v-bending: v-die bending and v-punch bending. In the testing process, the v-die bending was installed on the bottom holder of the universal testing machine, while the v-die punch was installed on the top side. The v-die punch speed is set according to the parameters of each sample. **Figure 2** shows the shape of the v-bending geometry and the bending testing process. The bending test matrix is presented in **Table 2.**

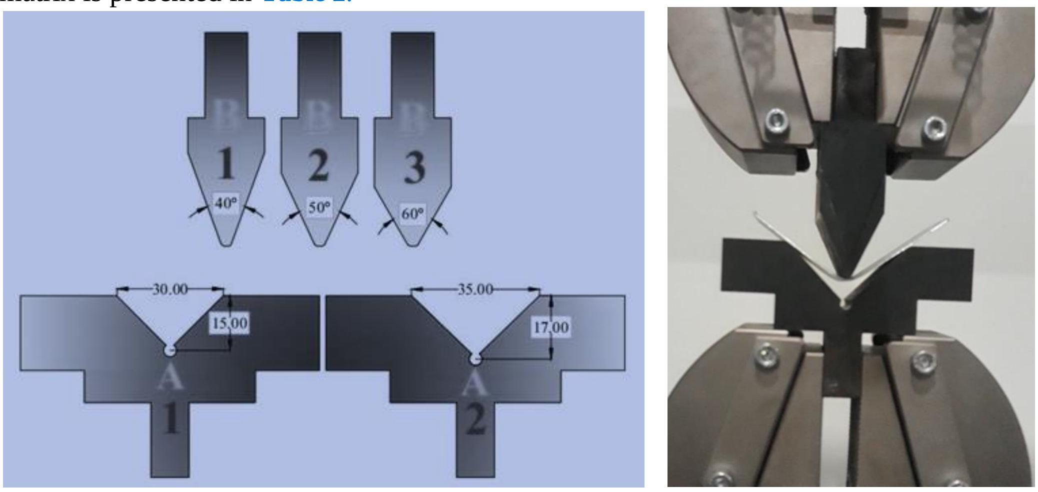



**Figure 2.** Geometry of V-die and V-die process applications

**Table 2.** Mechanical properties and chemical composition (%) of SGCC steel

| Parameter V-die bending | Sample number | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Opening *V-Die, L* (mm) | 30 | 30 | 30 | 35 | 35 | 35 |
| Angle *V-die punch,* ø (°) | 40 | 50 | 60 | 40 | 50 | 60 |
| Speed *Punch,* $V_b$ (mm/minute) | 30 | 30 | 40 | 40 | 50 | 50 |
| *Bending Force, F* (N) | 6500 | 6500 | 7000 | 7000 | 7500 | 7500 |

## 2.3. *Analysis of Variance*

Analysis of variance (*ANOVA*) is an interrelated statistical model and estimation procedure used to analyse differences between means [16]. *ANOVA*, or the law of total variance, is that the observed variance in a particular variable clustered into a component will be distributed to unequal sources of variation.

*ANOVA* in this study uses statistical software to simplify and get accurate results [17].

### *2.4. Bending work calculation*

Bending is a low-to a medium-volume technique for producing near-net shapes [18]. Parts that are typically lightweight and durable are usual [19]. Some process variances can be affected by material variations. The spring-back effect alters the angle of bending. There are many different ways to keep an eye on a process as it is happening. Brake forming and progressive forming are two additional techniques. Each curve is a setup (although sometimes, multiple bends can be formed simultaneously). Due to the vast number of setups and geometrical changes that occur during bending, it is difficult to plan for tolerances and bending defects in advance. Bending force calculation is needed to calculate the minimum required bending force. The bending force in the v-die bending process is carried out using equation 1 [4] [20].

$$F_b = \frac{b_s t^2 R_m}{w} \; Jika \; w/t \geq 10 \qquad (1)$$

$$F_b = \left(1 + \frac{4.t}{w}\right) \frac{b_s t^2 R_m}{w} \; Jika \; w/t < 10 \qquad (2)$$

Where $F_b$ is the magnitude of the bending force (N), bs is the width of the workpiece (mm), t is the thickness of the material (mm), Rm is the tensile strength (N/mm$^2$), and w is the width of the v-dies opening (mm). Calculation of material spring back angle (∅) and spring back factor ($k_R$) is calculated using equations 4 and 5. The geometry of the v-die bending process is presented in **Figure 3**.

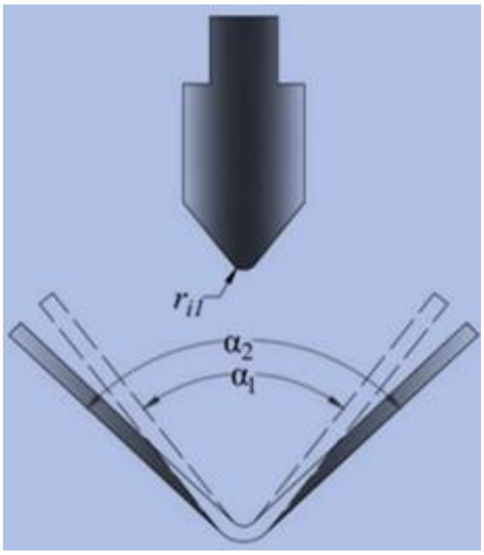



**Figure 3.** V-die bending process α1 bending process angle, α2 angle after bending force is released

$$\emptyset = \alpha_2 - \alpha_1 \qquad (4)$$

$$k_R = \frac{\alpha_1}{\alpha_2} \qquad (5).$$

## 3. RESULT AND DISCUSIONS

### *3.1. Analysis of bending forces and work*

A bending force is a force applied to a material's length. The bending force is applied to an occasion, region, or volume located at a distance from a fixed portion of the structure or component it is being decided to apply [21]. The ratio of material thickness to the width of the experimental workpiece is less than 10 (w/t < 10). This criterion fulfils equation 2 so that the calculation of the minimum force required is in accordance with this equation. Next, the calculation of the bending work is carried out using equation 3. The correction factor of 0.33 (1/3) is chosen in correcting the bending work [20]. Bending calculation data is presented in **Figure 4**. Based on the data for calculating the minimum bending force in **Figure 4**, information is obtained that the bending force during the test specified in **Table 2**.meets the criteria for

Equation 2 regarding the minimum calculation of bending work [20].

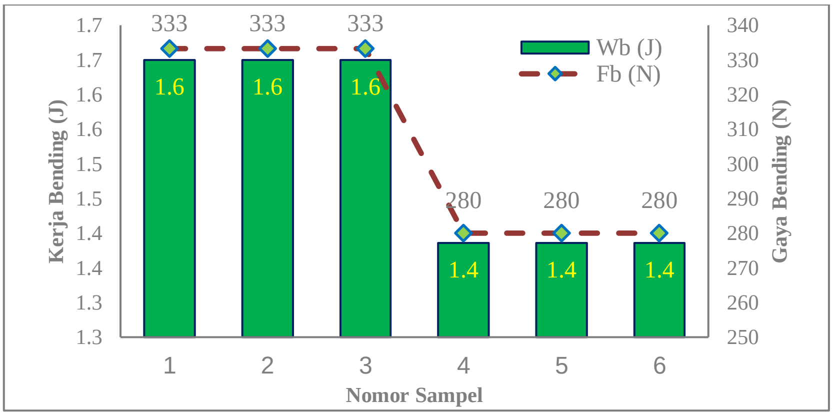



**Figure 4.** Force and bending work in V-die bending result

*2.1. Bending test analysis*

The bending test process is carried out by adjusting the speed of the v-die punch and the testing matrix in table 2. The galvanized steel plate subjected to the bending process is then measured using a bevel protractor. The results of the v-bending process on 6 (six) samples are presented in **Figure 5**. The angle measurement data from the v-bending test of galvanized material is presented in **Table 3**. Then the data is converted into degrees. Bending angle conversion results are used to analyze spring-back/spring-go angle data and spring-back factor data. The calculation of the degrees of spring-back/spring-go uses equation 4, while the calculation of the spring-back/spring-go factor uses equation 5 [22]. The calculation data for the degrees of spring-back/spring-go and the spring-back/spring-go factor is presented in **Figure 6**. **Figure 6**.a shows the analysis data of the spring-back/spring-go angles calculated in equation 4. From these data, it can be seen that the bending process using a v-die punch angle of 40$^o$ experiences a spring-back phenomenon.

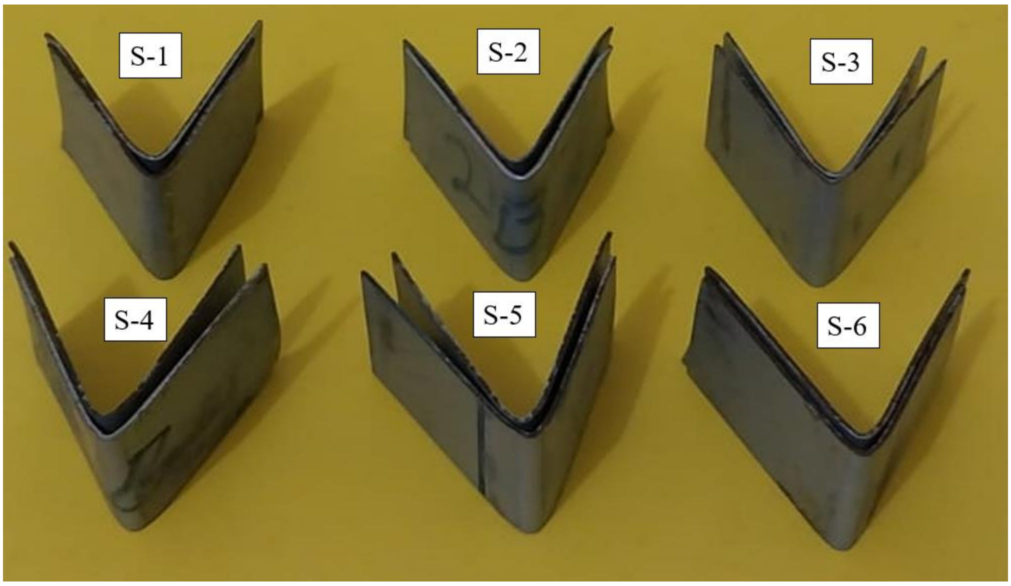


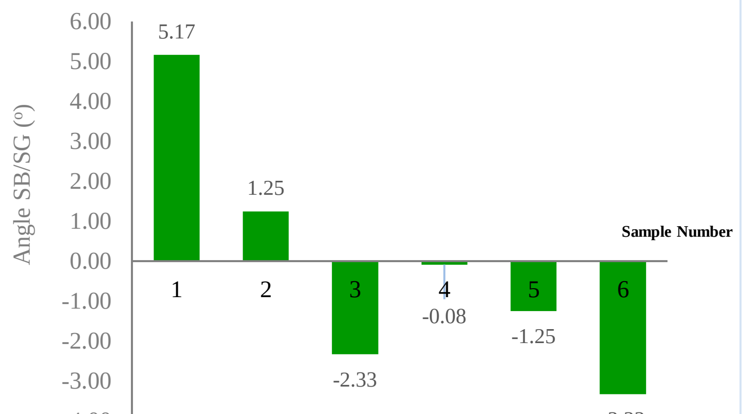

**Figure 5.** V-bending test results for 1.2 mm SGCC Galvanized steel material.

In contrast, the spring-go phenomenon affects all angles applied to use a v-die punch with an angle of 50$^o$ and 60$^o$. This condition is according to research [6]. In this study, it is known that the phenomenon of the spring-back angle occurs when the v-die punch angle is performed at less than 45$^o$. Meanwhile, the spring-go phenomenon occurs when the process is carried out at an angle of more than 45$^o$. This subsection describes the net results of the research without the data analysis process and the results of hypothesis testing. This section serves as a place to put the research results that have been found. Results can be presented with tables or graphs to clarify the results verbally.

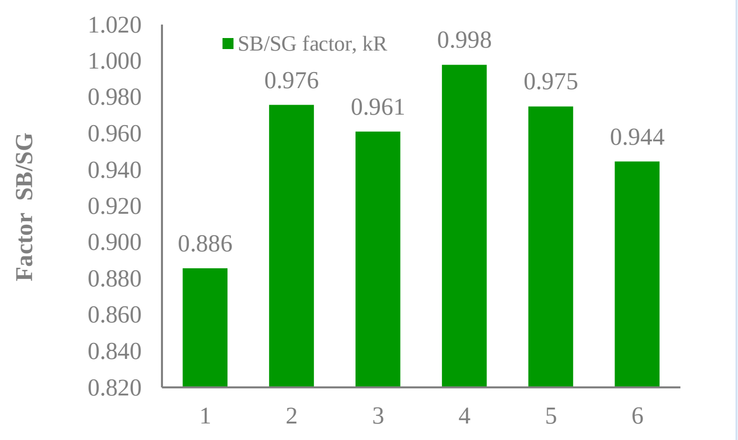
The discussion is the most important part that functions to answer research problems, interpret and narrate the findings, integrate findings from research into existing knowledge sets, discuss previous research results, modify existing theories or develop new theories. The spring-back/spring-go factor analysis data obtained that in the 4th sample, the spring-back/spring-go factor was 0.998. This was because the spring-back/spring-go angle in the $4^{th}$ sample was almost close to 0. The average factor spring-back/ spring-go implementation of the test is 0.96. This condition follows the data from [20] that carbon steel material has a spring-back factor of around 0.97. Galvanized material type SGCC (JIS G 3302) is a low carbon steel material SPCC-SD (JIS G 3141) which is coated with zinc through a hot dipping electroplating process [23] [18]. Spring-back/spring-go factor analysis data is presented in **Figure 6. b**.

**Table 3.** Galvanized material bending test data

| Sample Number | Opening *V-Die*, L (mm) | Angle *V-die punch*, ø (°) | Speed *Punch*, $V_b$ (mm/minuts) | *Bending Force* (N) | Bending angle data | |
|---|---|---|---|---|---|---|
| | | | | | Degree | Minuts |
| 1 | 30 | 40.00 | 30 | 6500 | 45 | 10 |
| 2 | 30 | 50.00 | 30 | 6500 | 51 | 15 |
| 3 | 30 | 60.00 | 40 | 7000 | 57 | 40 |
| 4 | 35 | 40.00 | 40 | 7000 | 39 | 55 |
| 5 | 35 | 50.00 | 50 | 7500 | 48 | 45 |
| 6 | 35 | 60.00 | 50 | 7500 | 56 | 40 |



(a)



(b)

**Figure 6.** V-bending test experimental results: (a) SB/SG angle, (b) SB/SG factor.

### 2.2. ANOVA Evaluation

*ANOVA* was performed to determine the response of the bending parameters to the spring-back/spring-go angles. The test data is evaluated using statistical software by entering the desired input and response variables [25]. Due to the large degree of freedom factor of 0 (zero), one-way *ANOVA* was chosen. *ANOVA* data using statistical software is presented in **Table 4**.

**Table 4.** Galvanized material bending test data

| Source | Parameter Bending | Adj SS | Adj MS | F-Value | Contribution |
|---|---|---|---|---|---|
| A | Opening *V-Die*, L (mm) | 12.76 | 12.760 | 1.52 | 11.6% |
| B | Angle *V-die punch*, ø (°) | 28.92 | 14.459 | 2.49 | 26.4% |
| C | Speed *Punch*, $V_b$ (mm/minuts) | 33.95 | 16.977 | 4.12 | 31.0% |
| D | *Bending Force* (N) | 33.95 | 16.977 | 4.12 | 31.0% |

Based on the ANOVA data in **Table 4**, it is known that v-die punch speed and bending force have the greatest contribution to the response variable.

## 4. CONCLUTIONS

The v-bending test research process using SGCC galvanized sheet steel material (JIS G-3302) with a thickness of 1.2 mm has been completed with the following conclusions:

a. Obtained the phenomenon of spring-back/spring-go angles that occur simultaneously. Spring-back shrinkage occurs when the v-die punch angle is less than 45°. Meanwhile, the spring-go phenomenon occurs when the v-die punch shrinkage is more than 45°.
b. The spring-back/spring-go factor affects the spring-back/spring-go angle. The smaller the spring-back/spring-go angle is close to 0 (zero), the spring-back/spring-go factor will be close to 1. The value of the spring-back/spring-go factor, close to 1 (one), indicates that the material tends to be stiffer. The more away from 1 (one) and close to 0 (zero), then shows a material that tends to be elastic.
c. Speed of v-die punch and bending force are the most influential input variables because they contribute to the response variable.
d. Next, v-bending research will be studied using the Taguchi experimental method approach with variations of the four variables using three levels of experimentation.

## AUTHOR'S DECLARATION

### Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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### Availability of data and materials

All data are available from the authors.

### Competing interests

The authors declare no competing interest.

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