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# Geometrical analysis of the V–Y advancement flap applied to a keystone flap

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**Summary Background:** The V–Y advancement flap and, more recently, the keystone flap are commonly used to cover skin defects. Both flaps allow for primary closure after advancement by substituting the initial defect for a narrower defect distributed over a greater length.

The first objective of this study was to develop a geometrical analysis of the V–Y advancement flap. The second objective was to explain the benefit of using the keystone flap compared to a single V–Y advancement flap.

**Material and method:** A geometrical analysis is proposed using a two-dimensional analysis in which the flaps are assumed to have a rigid-body behaviour. First, in the case of the V–Y advancement flap, a trigonometric relationship is defined between the distance of closure before and after advancement, thus implying the value of the flap's apex angle. Second, by considering the keystone flap as the association of three V–Y advancement flaps, the trigonometric relationship is applied to the keystone flap.

**Results:** In the case of the V–Y advancement flap, the optimal apex angles are between 20° and 60°. At less than 20°, the length of the flap increases in an exaggerated manner. At greater than 60°, the distance of closure, particularly at the apex of the flap where a corner stitch is performed, is greater than the distance of closure of the initial defect. In the case of the keystone flap, the width of the final defect around the flap is clearly smaller and more regular compared to the final defect around a single V–Y advancement flap.

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**Conclusion:** The geometrical analysis of the V–Y advancement flap in our description illustrates the major benefit of the keystone flap over a single V–Y advancement flap.

The V–Y advancement flap and, more recently, the keystone flap are commonly used in practice to cover skin defects. The purpose of using a V–Y advancement flap is to substitute a rectangular defect adjacent to the base of the flap for two parallelograms that are adjacent to each side of the flap. The height of each parallelogram is smaller than the width of the initial defect (Figure 1).

The keystone island flap, which was first proposed by Behan (2003),<sup>1</sup> is also an advancement flap that is used adjacent to an elliptical defect. However, the main difference compared with the V–Y advancement flap is the curvilinear trapezoidal shape of the keystone island flap, a name that is borrowed from architectural terminology (Figure 2).

The first objective of this study was to develop a geometrical analysis of the V–Y advancement flap to describe the trigonometric relationship of the defect before and after the advancement of the flap based on the value of apex angle of the flap. The second objective was to explain the benefit of the keystone flap, which is considered to be a combination of three V–Y advancement flaps, compared with a single V–Y advancement flap.

## Method

In this two-dimensional analysis, the flaps are assumed to follow a rigid-body behaviour. Not only is the non-linear and

viscoelastic behaviour of soft tissues unknown, but the influence of subcutaneous tissues is also poorly understood.

## Geometrical analysis of the V–Y advancement flap

Let a rectangular defect be  $BCC'B'$  with  $d = CC' = BB'$ ,  $D = CB = C'B'$  and  $d < D$  (Figure 3).

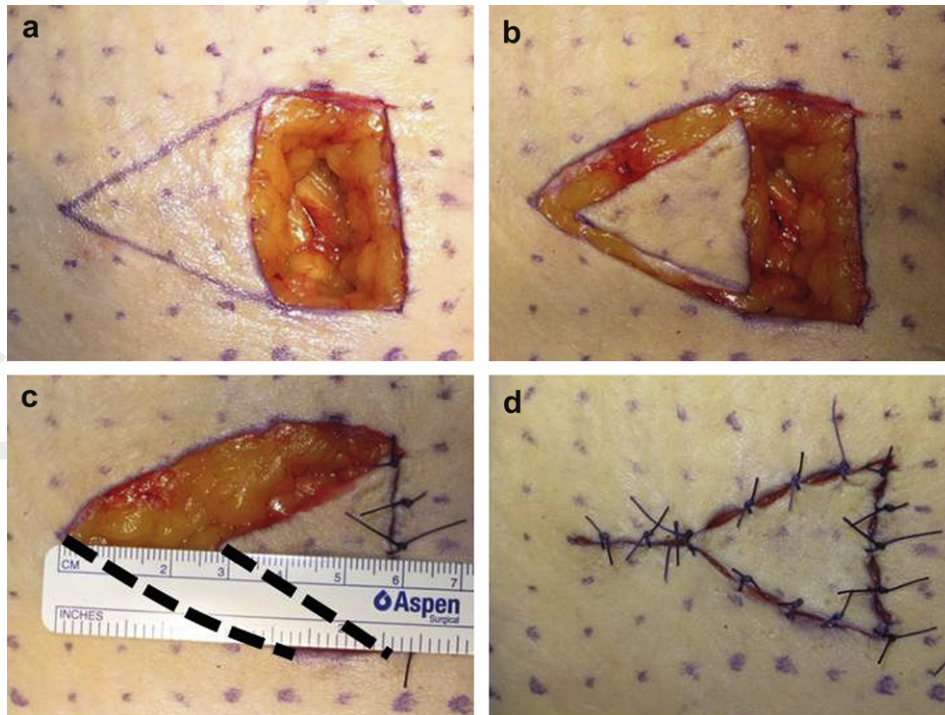
Let  $ABC$  be a V-shaped flap in the form of an isosceles triangle exhibiting an apex angle  $\alpha$ , a base  $BC$  and a height  $H$ .

The geometrical analysis of the V–Y advancement flap consists of studying two stages:

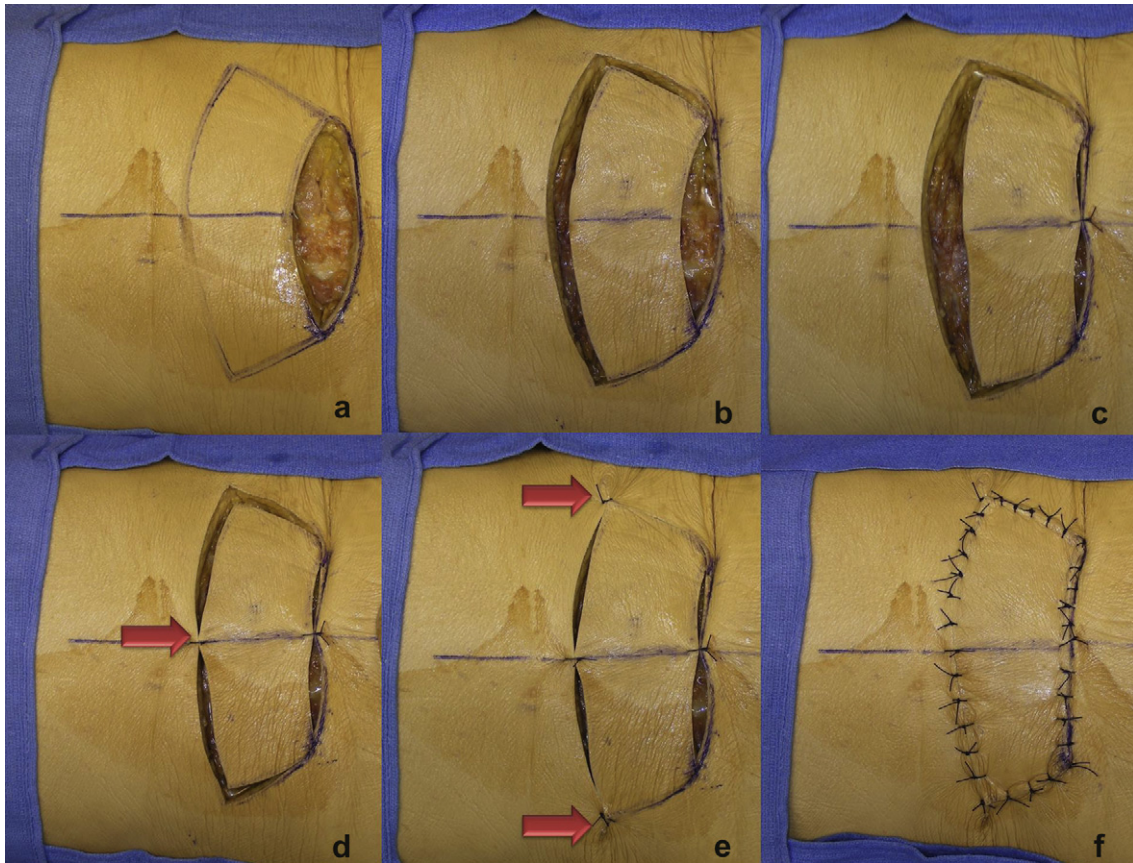
- the stage prior to incising the V-shaped flap (Figure 1a)
- the stage after suturing one side of the flap (Figure 1c).

The V-shaped flap moves from its original position ( $ABC$ ) to its final position ( $A'B'C'$ ) by a translatory movement of distance  $d$  along the horizontal axis. By displacing the V-shaped flap, the rectangular defect ( $BCC'B'$ ) adjacent to the base of the flap is replaced by two parallelograms, ( $AA'B'B$ ) and ( $AA'C'C$ ), that are symmetric with respect to the horizontal axis  $AA'$ . The areas of the defects before and after the advancement are clearly equal.

Let  $h$  be the height of each parallelogram. The parameter  $h$  also represents the minimal distance of closure between the cutaneous lips of the two new defects,



**Figure 1** Different successive phases of a V–Y advancement flap. a: rectangular defect adjacent to the base of the triangular flap. b: incision of the flap. c: advancement of the flap to cover the defect. d: final aspect with a Y shape.



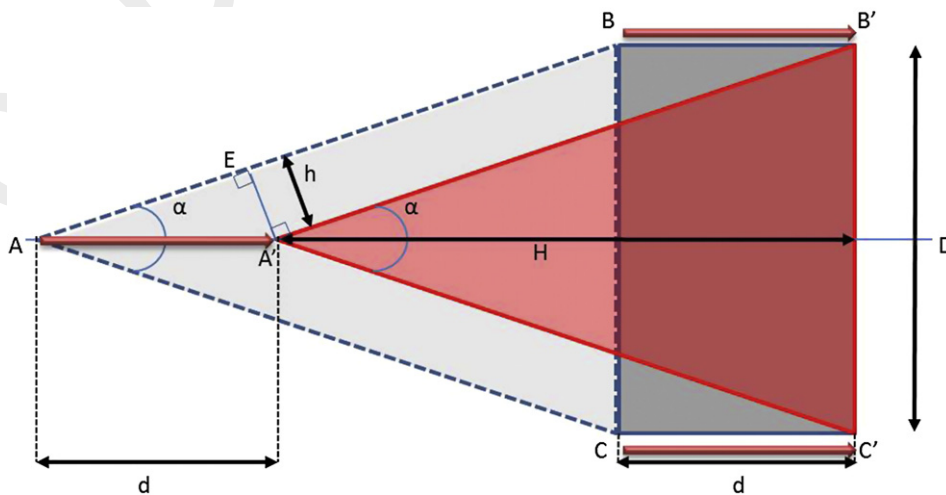
**Figure 2** Keystone flap design and realisation in a cadaver. a: design of the flap. b: skin incision. c: closure of the primary defect (arrow). d: closure of the defect due to the flap advancement (arrow). e and f: closure with 2 V–Y advancement flaps on the extremities of the flap (arrow).

whereas the parameter  $d$  is the width of the initial defect. The mathematical relationships between  $\alpha$ ,  $d$ ,  $h$  and  $H$  were identified.

### Geometrical analysis of the keystone flap

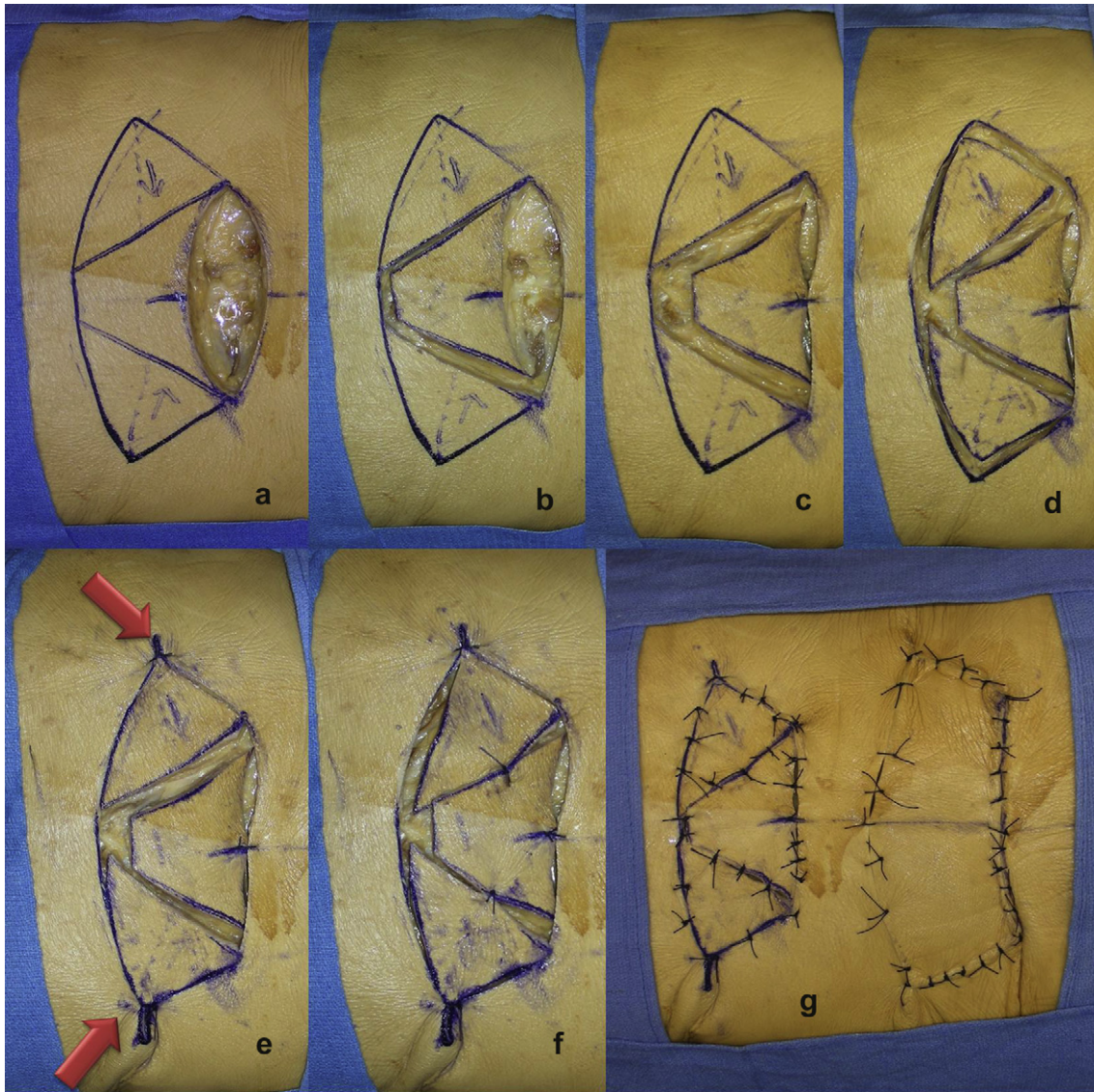
A keystone flap is considered to be a composite of three V–Y advancement flaps (Figure 4). Two lateral V–Y advancement

flaps,  $(A_2B_2C_2)$  and  $(A_3B_3C_3)$ , located at the extremities of the defect are separated by a median flap. The median flap is essentially an isosceles trapezoid with linear sides, although it can be considered to be a truncated V–Y advancement flap that is defined by the  $\alpha$ -angle of its virtual apex  $A_1$  (Figure 5). Because the lateral triangles are not isosceles, the angle between apex  $A_2$  and  $A_3$  is the sum of  $\delta$  and  $\gamma$ , which are the angles at either side of the heights  $A_2H_2$  and  $A_3H_3$  (Figure 5b).



**Figure 3** Geometrical basis of the V–Y advancement flap.





**Figure 4** The keystone flap is divided into 3 V–Y advancement flaps on a cadaver. a: design of the 3 flaps prior to the skin incision. b: skin incision of the median flap that is similar to a triangular flap with a truncated top. c: advancement of the median flap. d: skin incision of the lateral flaps. e: advancement of the lateral flaps to close the lateral defect adjacent to the median flap. f: closure of the lateral defect adjacent to the median flap. g: complete closure of the flap. The final shape of the flap (right) is comparable to the original keystone flap (left).

We define four distinct stages in the keystone flap procedure (Figures 4 and 5):

- initial stage: design of the V–Y advancement flaps (Figures 4a, b and 5a);
- intermediate stage n°1: displacement of the median flap (Figures 4c, 5b and c);
- intermediate stage n°2: displacement of the two lateral flaps (Figures 4d, 5d and e); and
- Final stage: closure (Figure 5f and g).

During the first intermediate stage, the median flap is moved by a distance  $d$  to cover the defect. Similar to that of the V–Y advancement flap, the displacement of the median flap substitutes the initial defect with two

lateral defects (Figure 5c). Let  $h$  be the width of each new defect.

During the second intermediate stage, the two lateral defects that result from the median flap displacement are covered by moving the two lateral flaps using translatory movements of distance  $h$  along axes parallel to  $A_2H_2$  and  $A_3H_3$  (Figure 5c and d). Following the same principle, a new defect appears on each side of the triangular flap (Figure 5d). Because the triangle is not isosceles, the size of the defect depends on the side of the triangle. We define  $i$  and  $j$  as the widths of the defects on either side of the lateral triangular flap.

From the mathematical model developed above for the V–Y advancement flap, the relationships between  $\alpha$ ,  $\delta$ ,  $\gamma$ ,  $d$ ,  $h$ ,  $i$  and  $j$  were identified.

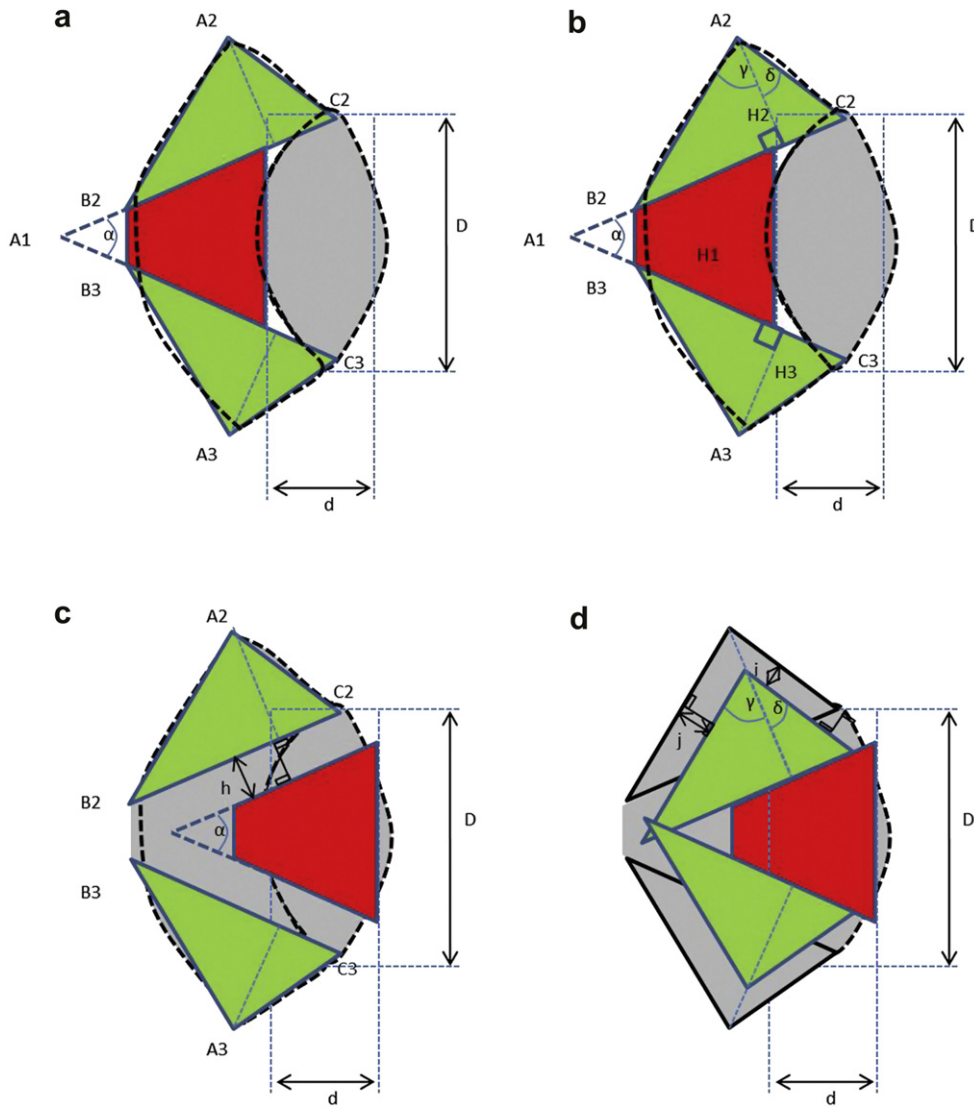


Figure 5 Modelling of the keystone flap as an association of 3 flaps.

## Results

### V-Y advancement flap modelling

The tangent function of the half apex angle is defined by the following equation:

$$\tan\left(\frac{\alpha}{2}\right) = \frac{D}{2H}. \quad (1)$$

Using Equation (1), the  $H/D$  ratio is defined by the following relationship:

$$\frac{H}{D} = \left( \frac{1}{2 \tan\left(\frac{\alpha}{2}\right)} \right). \quad (2)$$

The height  $h$ , the width  $d$  and the angle  $\alpha$  are trigonometrically related according to the following formula:

$$\frac{h}{d} = \sin\left(\frac{\alpha}{2}\right). \quad (3)$$

A graphical representation of the variations in ratios  $H/D$  and  $h/d$  at different  $\alpha$ -values based on Equations (2) and (3) is shown in Figure 6. The  $h/d$  (blue) and  $H/D$  (red) curves vary in opposite directions with respect to  $\alpha$ . The  $H/D$  value decreases sharply as  $\alpha$  increases from  $0^\circ$  to  $20^\circ$ , which implies a considerable increase in the length of the V-Y flap. The blue curve shows that the value of parameter  $h$  increases with increased values of angle  $\alpha$ . Equation (3) implies that the height  $h$  is necessarily smaller than the width  $d$ , which is the main benefit of the V-Y flap. Nevertheless, as shown in Figure 2, if the length of the closure on each side of the flap is equal to  $h$ , the length of the closure at its apex, where a corner stitch is performed, is equal to  $2h$ . For  $\alpha$ -values of  $60^\circ$  or more (Equation (3) and blue curve), the parameter  $h/d$  is equal to or greater than 0.5, which implies that the total length of the closure at the apex is equal to or greater than  $d$ .

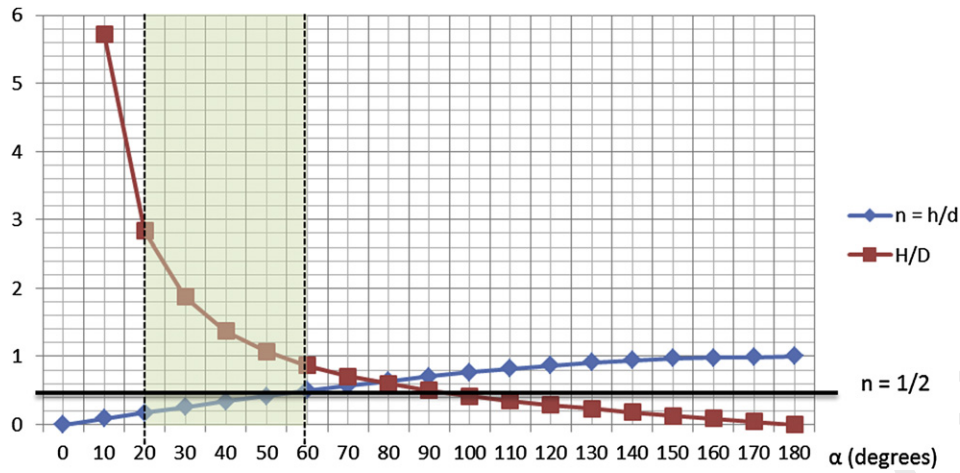


Figure 6 Graphic representation of  $\alpha$  and the ratio  $H/D$  with respect to  $h/d$ .

In conclusion, the optimal values of  $\alpha$  are between  $20^\circ$  and  $60^\circ$ .

### Keystone flap modelling

During the first intermediate stage,  $h$ ,  $d$  and  $\alpha$  are trigonometrically related according to Equation (3), as described above.

During the second intermediate stage,  $i$  and  $j$ , that is, the widths of the defects on each side of the lateral triangular flap, are related to  $h$ ,  $\delta$  and  $\gamma$  according to the following formulas:

$$i = h \cdot \sin(\delta). \quad (4)$$

and

$$j = h \cdot \sin(\gamma). \quad (5)$$

By combining Equation (3) with Equations (4) and (5), we obtain the following:

$$i = d \cdot \sin\left(\frac{\alpha}{2}\right) \cdot \sin(\delta). \quad (6)$$

and

$$j = d \cdot \sin\left(\frac{\alpha}{2}\right) \cdot \sin(\gamma). \quad (7)$$

Equations (6) and (7) show that the widths of the defect after the displacement of the three flaps are decreased by a factor of  $\sin(\delta)$  for the height  $i$  and by a factor of  $\sin(\gamma)$  for the height  $j$  relative to a single V–Y advancement flap (Figure 7). The width of the final defect surrounding the flap varies between  $i$  and  $i + j$  at the apex of the lateral triangular flaps.

### Discussion

#### V–Y advancement flap

The V–Y advancement flap was first described by Dieffenbach in 1845. The purpose of this advancement flap is to substitute a rectangular defect adjacent to the base of the flap with two parallelograms next to each side of the flap. Multiple variations of the V–Y advancement flap have been described with a variety of deep, unilateral and

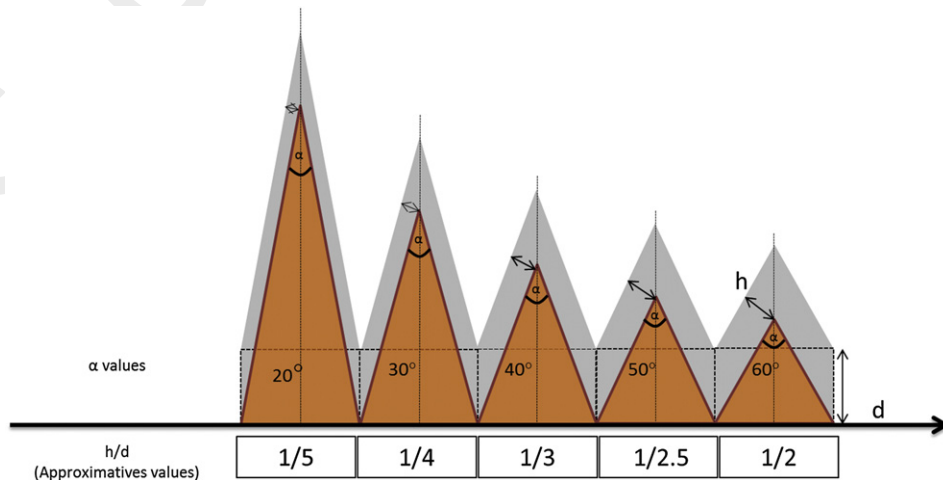


Figure 7 Values of  $h$  with respect to  $\alpha$  after an advancement of distance  $d$  of the V–Y flap.



bilateral pedicles.<sup>2,3</sup> Many changes to its design, including the classic triangular form, a bilaterally opposed design,<sup>4-7</sup> an extended form,<sup>8</sup> multiple flaps with a Burrow's excision,<sup>9</sup> a flap-in-flap configuration<sup>10</sup> and a Pacman flap design<sup>11</sup> have been described. Commonly, the flap advances in the various designs have been based on the elasticity of the flap's vascular support, although an advancement with a rotational component is also possible.<sup>3,7</sup>

Mathematics plays an important role in the design and understanding of local flaps. In 1963, Limberg published a book in which he provided detailed analyses of the changes that occur on the skin surface as various plastic procedures are performed. Limberg analysed surface changes using mathematical methods, and in the cases of a rhomboid flap or Z plasty, the surface changes were demonstrated using paper models.<sup>12</sup> Many types of flaps have been previously analysed geometrically<sup>13,14</sup> or according to a finite element analysis,<sup>15</sup> but there are few descriptions of the V–Y advancement flap.<sup>16</sup> The geometrical analysis of the V–Y advancement flap in our study clearly shows a simple relationship between  $\alpha$  (the value of the apex angle of the flap),  $d$  (the width of the primary defect) and  $h$  (the width of the secondary defect) (Eqn. (3)). In particular, this analysis demonstrates the following (Figure 6):

- the inverse relationship between  $\alpha$  and  $h$ ,
- the optimal values of  $\alpha$  and
- the relationship between the width of the defect before and after the advancement of the flap  $h/d$  as a function of  $\alpha$ .

The optimal values of  $\alpha$  are between 20° and 60°. At less than 20°, there is a considerable increase in the length of the flap (Figure 6). This effect has been demonstrated previously by Andrades.<sup>16</sup> For a value of  $\alpha$  equal or greater than 60°, the suture distance at the apex of the flap is greater than the width  $d$  of the initial defect, thereby significantly reducing the benefit of using the flap. Therefore, a  $\alpha$ -value of approximately 40° appears to be a good compromise between the length of the flap and  $h$ . In a tissue with low elasticity,  $\alpha$  should be minimised to reduce  $h$ .<sup>17</sup>

It is interesting to note the values of the ratio  $h/d$  with respect to particular values of  $\alpha$  (Figure 7):

- when  $\alpha$  equals 30°,  $h/d$  is approximately 1/4,
- when  $\alpha$  equals 40°,  $h/d$  is approximately 1/3 and
- when  $\alpha$  equals 60°,  $h/d$  is equal to 1/2.

## Keystone flap

The keystone design perforator island flap was first described in 2003,<sup>1</sup> and there is sufficient evidence that it can now be routinely used in clinical practice particularly when random flaps are unreliable, such as in cases involving the lower leg<sup>18-20</sup> or irradiated tissue.<sup>21</sup> Four types of keystone flaps have been described:<sup>1</sup> when a deep fascia incision is needed (types I and II), when there is a possibility of a direct closure or when a skin graft is necessary (types

IIA and IIB), when a double keystone flap is used (type III) and when up to 50% of the flap needs be undermined sub-fascially (type IV). This article is only concerned with types I and II.

In architectural terminology, a keystone is the wedge-shaped stone piece at the apex of a masonry vault or arch and is the final piece placed during construction; the keystone locks all of the stones into position, allowing the arch to bear weight. Similarly, the shape of the keystone flap appears to lock the median part of the flap into place.<sup>1</sup>

The popularity and reliability of the keystone design perforator island flap is due to its particular design:

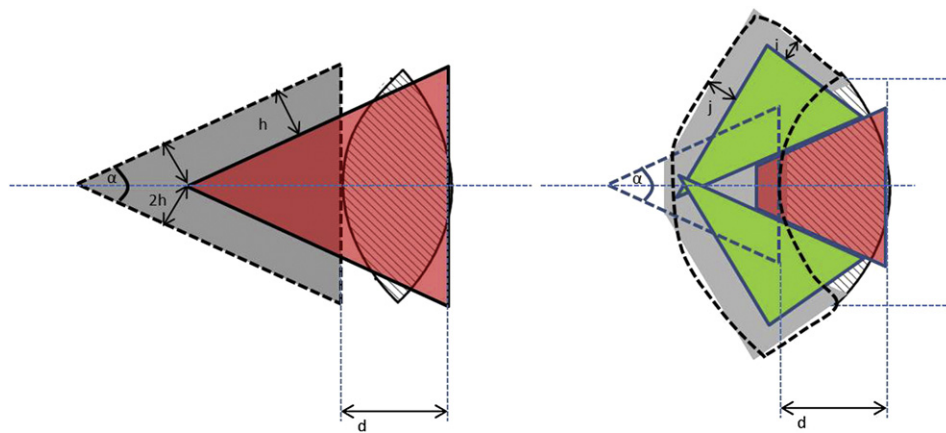
- because it is an island flap, there is no cutaneous bridge to restrict mobility.
- the flap is, to the greatest extent possible, designed within dermatomal precincts, including superficial and deep veins, fascial and muscular perforators or cutaneous nerves, for the best possible vascularisation.<sup>22-24</sup>
- According to the author,<sup>1</sup> the curvilinear trapesoidal design of the keystone integrates two V–Y advancement flaps oriented end to side. The advancement of the flap, which is necessary for wound closure, opens a lateral defect that is long and narrow. Suturing the angles in a V–Y fashion further reduces the surface to be closed and locks the flaps into their final positions.

Our study proposes to divide the keystone flap into three, instead of two, V–Y advancement flaps. The benefit is twofold. First, considering the keystone flap to be the assemblage of three V–Y advancement flaps is structurally closer to architectural terminology. Nevertheless, it is interesting to note that in surgery, the median flap is locked by the lateral flaps, whereas in architecture, the keystone locks all of the stones into position. Second, our analysis clearly shows that the distribution of the defect around the flap is smaller with a more uniform width compared to the advancement of a single V–Y flap with the same apex angle value ( $\alpha$ ) (Figure 7). Although the shape of the three flaps in our study is arbitrary, the flaps have been designed to be superimposed on the original shape of the flap as originally described by Behan.<sup>1</sup> In our model of the three flaps, the values of  $\alpha$  are approximately 45°, the values of  $\delta$  are approximately 30° and the values of  $\gamma$  are approximately 55°. Using Equations (2), (8) and (9), we estimate the values of  $h$ ,  $i$  and  $j$  as follows (Figure 6d):

- $h \approx 0.4 \times d$ ,
- $i \approx 0.2 \times d$  and
- $j \approx 0.3 \times d$

In the case of the keystone flap, the width of the final defect around the flap is between  $i$  and  $i + j$ , that is, between 0.2  $d$  and 0.5  $d$ , at the apex of the lateral triangular flaps. In the case of a single V–Y advancement flap with an apex angle value equal to  $\alpha$  (Figure 8), the distance to the closure on each side of the flap is between  $d$  and  $2d$ . This simple model illustrates the major benefit of the keystone flap versus a single V–Y advancement flap with a smaller and more regular distance to closure after the advancement.





**Figure 8** Width of the defect according to the type of flap. For the keystone flap, the maximum distance of closure occurs at the apex of the lateral triangular flap and is equal to  $i + j$ . For the V–Y advancement flap, the maximum distance of closure occurs at the apex of the flap and is equal to  $2h$ .

Nevertheless, our analysis has many limitations. It does not take into account the viscoelastic behaviour of the skin and its anisotropy. These limitations explain the inconsistency in the management of the central defect after the advancement of the median flap and the superposition of the lateral flaps. Despite this, the final shape of the flap after suturing in our modelling is comparable to the final shape in practice when the tissue elasticity is low, such as when dealing with scalps<sup>1</sup> or non-fresh cadavers (Figures 4 and 5).

More additional complex modelling using finite element analysis is underway that considers the skin as an isotropic non-linear elastic homogenous tissue and that uses finite element analysis.

## Conclusion

The geometrical analysis of the V–Y advancement flap presented here involves simple modelling but has the advantage of not requiring complex mathematics. The skin is treated as rigid tissue without deformation during modelling. Although this does not reflect reality, it helps the surgeon to understand the relationship between the size of the defect before and after V–Y flap advancement according to the value of its apex angle. It also illustrates the major benefit of the keystone flap over a single V–Y advancement flap with a smaller and more regular defect after advancement.

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