ICUC One-Page Paper

Fracture fixation using cerclages

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The use of cerclages was condemned during decades based on the erroneous assumption that the cerclage would strangulate bone circulation. We understand today that most of the failures attributed to vascular strangulation were shortcomings of understanding biomechanics and biology of fixation and the application thereof. Fig. 1 and 2 are samples of recent successful application of cerclages fulfilling different functions in fracture fixation. The cases shown are extracted from the ICUC® database of continuous, complete, unchanged and audited recordings. In the following the basic and special mechanics and biomechanics as well as biological aspects and application are dealt with in so called one-page papers.

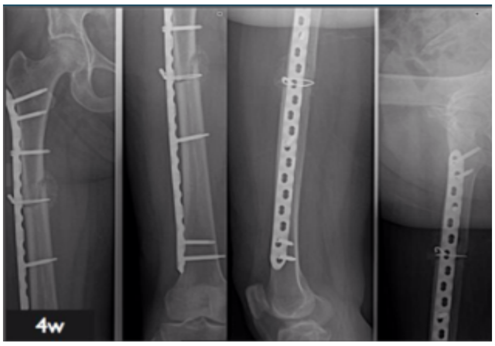

Fig. 1 Cerclage including the plate in a short oblique fracture. *Here cerclage is used for reduction and maintenance thereof. A twisted cerclage wire was used for reduction and fixation. (extracted from the ICUC®app database)*

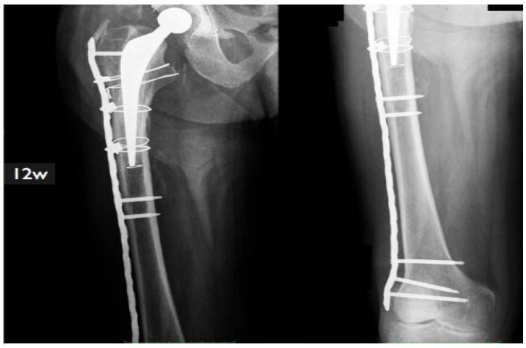

Fig. 2 Cerclages provide essential help in the treatment periprosthetic fractures. *The cerclage cables were used for reduction and fixation. They help where for instance plate screws would collide with the shaft of the prosthesis. (extracted from the ICUC®app database)*

Cerclage mechanics, basic aspects

The successful use of cerclage requires attention understanding the mechanical limits. In the following the most relevant characteristics are discussed with spring back and loose-lock as new elements to be considered in internal fixation.

The cerclage consists of a loop that includes bone fragments with or without additional splinting implants like plates, nails or shaft of a prosthesis. The loop consists usually of an wire with a knurled connection, or of a cable with a crimped connection. For biological reasons we do not consider straps here.

The cerclage wires are made of annealed steel that is characterized by its ductility i.e. large deformation before breakage occurs. This deformability is important when the knurled connection of a wire loop is produced. The deformability of cables made of titanium, with its excellent tissue compatibility and larger flexibility but smaller plastic deformation, depends mainly on the stranded structure of the cable.

Traction produced Fig. 3 demonstrates the effect of wire diameter and cable on traction produced. In respect to the latter the strength of the connection depends on the type of application (spring back or plastic deformation). Cutting and bending down have a strong effect on remaining traction after application as the plastic deformation at application of the knurl has (Fig. 4). The data on fatigue is crucial, here again the cable stands out (Fig. 5).

The strength determines the maximal load that can be applied without breakage or irreversible deformation. Strength plays an important role in cerclage fixation. The strength of the wire loop is limited by the weaker element of wire breakage or unwinding of the knurled connection. The knurled connection of a wire loop may unwind under load either elastically when not properly tightened, or plastically under excessive load. The cables and their crimp connection are stronger.

The stiffness determines the amount of deformation under load. Stiffness depends upon material and especially structure.

The elongation of a solid steel wire under traction is small but unwinding of the knurl results in a loose lock situation (see below). With its low bending stiffness the cable adapts better to the shape of the bone cross section and helps to keep fragment tips in place (Fig. 6). The elongation under load of a cable is somewhat larger than the one of a solid wire. This depends on its stranded structure and on the larger flexibility of the titanium when compared to solid wire made of steel.

The lever arm determines the momentum that a given force exerts. The larger the lever arm the stronger the effect of the loop. Therefore, cerclage loops need to be well spaced. This demand collides with the one of avoiding the tip of a fragment end in order to avoid its breakage; a balanced compromise is therefore needed.

Long spiral provide large leverage while leverage of short oblique fractures is small. Therefore, the cerclage provides good strength in the former. A point to consider is that the leverage of fragmented bone is much smaller than in simple fractures. (Fig 7)

The bone is an important partner when considering cerclage fixation. The function of the cerclage loop comprises beside the mechanical characteristics of the loop also the one of the bone. While cortical bone is strong and resists, the pressure exerted by a cerclage loop may cut into spongy bone.

The shape of bone fragments fixed by cerclage plays an important role. When considering the strength of a cerclage fixation the weaker element often is the bone due to its small cross section near the tip of a fragment end. Therefore the position of the cerclage loop needs to avoid the region near the tip of a fragment end. A distance of about 1 cm from the (full cortical thickness) tip of a fragment end to the position of the cerclage is a rule of thumb.

We call *“loose-lock stability”* a third type of stability beside absolute stability, i.e. compressed fragment contact, and elastic stability, i.e. a (small) gap allowing reversible displacement under load. Loose-lock needs consideration especially in respect to cerclage fixation. Under condition of a loosely applied or loosened cerclage loop the fragment can under load displace with little resistance until the loop “engages” and rigidly limits further displacement. This type of fixation is also typical for locked nailing where the locking screw engages after a certain play within the transverse hole in the nail. A loose-lock stability also occurs when biological loosening at an interface between implant and bone allows some play at the interface. **Loose-lock stability exerts an important effect on healing because the range of loose displacement may allow induction of bone repair while the locked range prevents too large a deformation (strain) of the repair tissue and thus prevents nonunion due to excessive strain.**

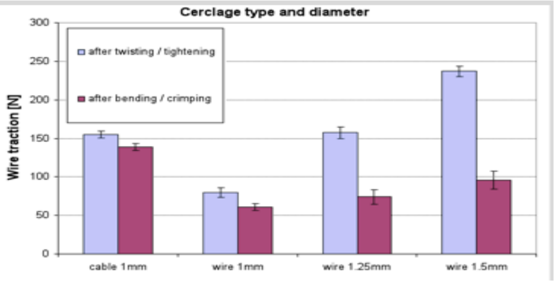

***Fig. 3 Comparison of stabilization using twisted wires of different diameter or crimped cable**. The applied traction increases with 3rd power of the wire diameter. bending down the knurl may result in appreciable loss of traction. the crimping of the cable produces minimal loss. The remaining traction is largest with crimped cable.. (D. Wähnert et al. 2011)*

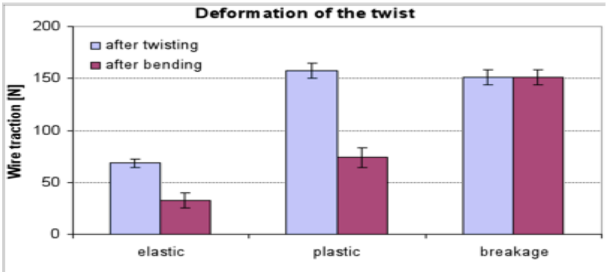

***Fig. 4 Wire traction after twisting** to elastic limit, to plastic limit and after breakage when exceeding twisting torque. When twisting is stopped within the range of elastic deformation only about half of the possible traction is reached and after bending down a small amount of traction is left. When twisting into the plastic range 150 N traction are reached and after bending down about 75 N traction remain active. When twisting until breakage the same amount of traction is reached and without the need of bending down the full amount is left active. (D. |Wähnert et al. 2011)*

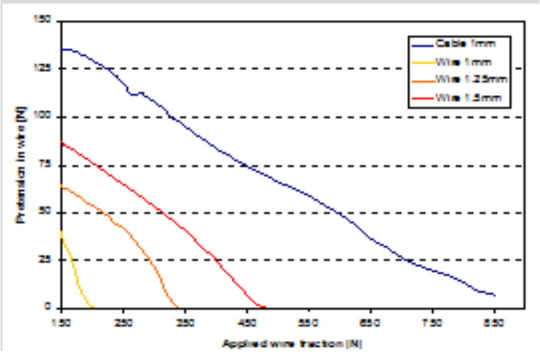

***Fig. 5 Fatigue test**, three sizes of steel wire and a titanium cable are tested. Loss of pretension for different wire diameters and a cable cerclage under cyclically increasing cerclage tension. Pretension is displayed on the y-axis. On the x-axis the cerclage tension applied during the test is shown. The cable cerclage provided a lasting pretension even under higher tension applied compared to the wire cerclages. (D. |Wähnert et al. 2011)*

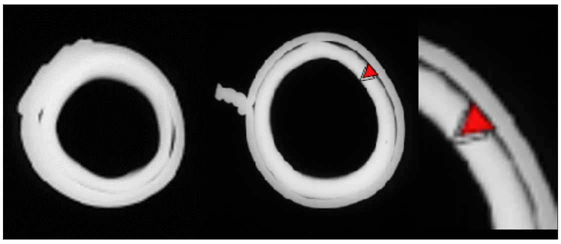

***Fig. 6 Form fit of cerclage and bone**. LEFT: A cable adapts snugly to the shape of the bone surface except flat or concave surfaces. RIGHT: Due to its bending stiffness the wire tends to stand off from surfaces with lower curvature. The tip of a fragment may therefore not be stably fixed before further displacement is limited (loose-lock situation) (Fernandez pers. comm.)*

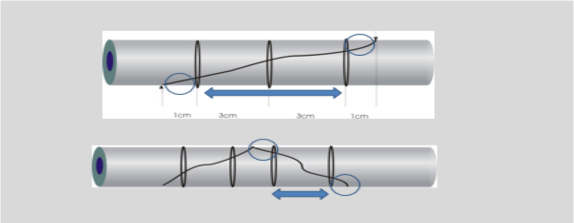

***Fig. 7 Leverage of cerclage** depending on length of the fragments and with it on spacing of the outer cerclages within a fragment. ABOVE Simple and long fragment provides large lever arm and good strength. BELOW: small lever arm within each additional fragment resulting in small spacing and strength though the spacing of the outermost cerclages would give the impression of large spacing*

Cerclage mechanics, special aspects

Some mechanical aspects of cerclage require special attention to allow taking full advantage when reducing and fixing fractures. The goal is to apply and maintain enough traction to keep the fracture fragments aligned and in stable position in relation to each other (Fig. 8). Failures, which were earlier on attributed to strangulation of blood supply, can often be traced back to improper use and therefore insufficient mechanical performance of the cerclage.
When considering using cerclage instead of lag screws we consider the fact that multiple fragments do not lend themselves to fixation by lag screws, which are independent from plates,
- either the application of the mentioned lag screws goes along with considerable tissue trauma
- or the presence of the stem of a prosthesis blocks the medullary cavity

The cerclage offers limited strength and is often applied in a way that results in unstable fixation from the very beginning on. The result is further loosening due to bone surface resorption induced by micro-motion (Ganz et al. 1975, Stadler et al. 1982)
The following elements need to be considered and appropriate action needs to cope with them:

- Cerclage loops that stabilize two fragments need to be spaced as much as possible to provide good leverage that for a given load reduces traction within the cerclage wire (Fig. 7).
- The limitation to such spacing stems from the danger to break peaked fragments when the cerclage is placed at the fine tip of the fragment.
- It goes without saying that the very small area of contact of the cerclage wire results in high stress of the contacted bone. But within the range of mechanically tolerated stress maintained pressure does not induce resorption (Perren et al. 1969).
- When tightening the cerclage wire producing a knurl the elastic wire presents a spring back action (Fig. 9). Thus if the wire is tightened within the elastic range only the cerclage loop is loose from the beginning on producing a loose-lock fixation
- The procedure of application of the cerclage wire is critical in respect to the tension achieved (Fig. 9 –13).
- The observation of bone loss at the surface, which is in contact with the cerclage, is not a reaction to high pressure but to instability due to insufficient pretension allowing micro-motion- induced bone resorption.
- Tightening the knurl well into the range of plastic deformation (Fig. 9) results in tightly maintained traction in the wire that results in centripetal compression for reduction and maintained fixation.
- Similar considerations apply to the use of crimped cables. Crimping a well pre-tensioned cable using a crimping technology that withstands pull out is the solution.
- The wire loops, which are not applied perpendicularly to the long axis of the bone, will adjust their position under load and become loose, once again a loose-lock situation. This statement applies especially to cerclages including plates (low friction between steel components).
- The former use of plaster “protecting” cerclage fixation must be challenged because its protecting effect is scares. It may even add to load due to inertia. The additional immobilization combining the disadvantages of conservative and surgical treatment is unfortunate.
- Using simple vs. double loops is demonstrated in Fig. 14 and its effect is shown in Fig. 15.

Conclusion: The cerclage technique offers substantial help for specific situations (like periprosthetic fractures) when applied providing maintained stable fixation and avoiding surgical trauma.

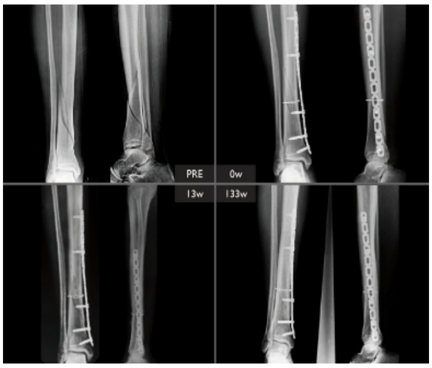

__Fig. 8 Long spiral fracture reduced and fixed using a cerclage__. The splining plate provides protection from overload and allows early recovery of painless function (from ICUC® database).

__Fig. 9 Elastic and plastic deformation of the wire and breakage__: increasing amounts of twisting torque applied result in the pictures from left to right. LEFT: too early release results in spring back. middle proper plastic deformation. RIGHT: after breakage the traction in the wire may be maintained (Perren et al. 2011).

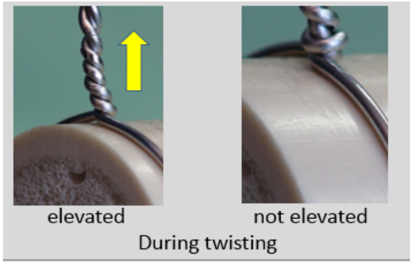

__Fig. 10 Effect of elevation during twisting.__ LEFT: To produce a symmetric windings of the knurl traction must be applied to keep the knurl elevated while twisting. RIGHT: Without traction one wire may wind around the other wire which remains straight. Less traction is to be expected. (Perren et al. 2011

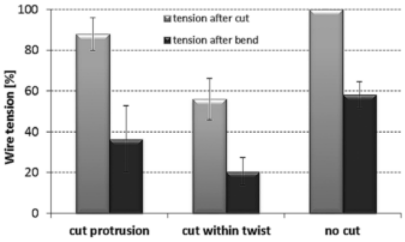

__Fig. 11 Remaining wire tension__ after different cutting procedures compared to initial tension after the twisting procedure. Cut wire ends (protrusion) - cut distal to the twist, cut within the twist - cut at three turns, no cut. Bars indicating mean ± standard deviation (D. Wähnert et al. 2011).

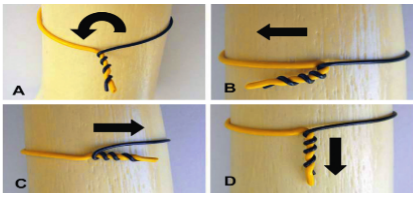

__Fig. 12 The influence of the bending direction__ on the quality of the twist. A: The black arrow indicates counter clockwise twisting. B: If the twist is bent forward, the black wire is secured against untwisting by the last turn of the other wire. C: If the twist is bent backward, it partially opens. The last turn of the black wire slides along the yellow wire, leading to loss of pretension. D: Perpendicular bent twist (D. Wähnert et al. 2011)

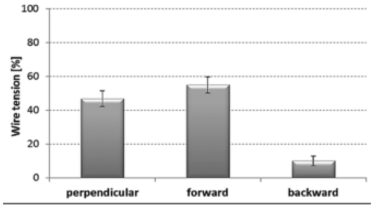

__Fig. 13 Influence of the bending direction__ of the twist on the pre-tension in the cerclage. Remaining Cerclage tension in % in relation to the initial cerclage tension after twist securing. Bars indicate mean ± Standard deviation (D. Wähnert et al. 2011).

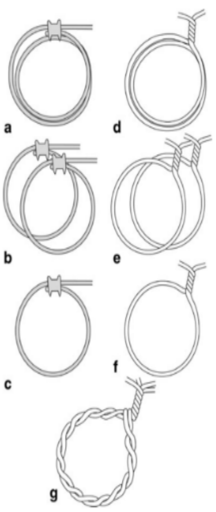

__Fig. 14 Cerclage configurations.__ Schematic view of the seven cerclage configurations compared in this study. a One double-looped 1.7-mm cable cerclage closed by a crimp. b Two single-looped 1.7-mm cable cerclages, each closed by a crimp. c One single-looped 1.7-mm cable cerclage closed by a crimp. d One double-looped 1.5-mm wire cerclage closed by a twist. e Two single-looped 1.5-mm wire cerclages, each closed by a twist. f One single-looped 1.5-mm wire cerclage closed by a twist. g Two braided 1.5-mm wire cerclages looped once around the bone and closed by a twist (M Lenz et al. 2013)

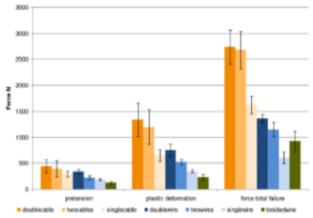

__Fig. 15 Pretension, load at onset of plastic deformation and load at total failure__. Mean wire tension values for the different cerclage configurations and types are displayed in (N). Error bars indicate standard deviation. Double-looped cables performed significantly better (p<0.05) in all tested modalities compared to single-looped cables (M Lenz et al. 2013).

Cerclage biology

Problems and Solutions, an overview

Preamble:

Cerclage can offer substantial help for reduction and fixation of fractures. It can overcome problems of present armamentarium particularly in the treatment of periprosthetic fractures. For decades the use of cerclage was condemn because it would “strangulate blood supply”, fact or a myth? The following addresses aspects of blood supply as well as of biological loosening of the cerclage.

Problem:

Cerclage was early on a frequently used technique for fracture treatment. It was obvious, that e.g. a long spiral fracture would profit from simple transverse loops pushing the fragments together. Thus, not only reducing but permanently stabilizing with cerclage appeared to be a favorable solution. Still the results of internal fixation depending alone on cerclage were all too often unsatisfactory. Lack of mechanical strength and secondary instability due to biologically induced instability were the main shortcomings. The poor results were often attributed to strangulation of blood supply in spite of earlier observations (Wilson et al. 1985, Nyrop et al. 1990)

Solution:

Recent observations question the all too easy voiced and accepted theory of vascular strangulation. Histology (Fig. 18) demonstrates that cerclage loops applied avoiding gross soft tissue stripping exert no relevant strangulation. The blood vessels might be squeezed by the cerclage loop at entry of bone. Due to the radial orientation of the blood vessels entering along muscle fibers (Fig. 16) this effect is small. Any implant to bone contact impedes locally the blood supply of bone, “contact damage”. For wires and cables the contact is less than a millimeter wide and its effect is superficial and mitigated by diffusion (Fig. 18).

The reason why the blood supply is not strangulated in spite of a closely fitting wire or cable relies on the fact that the blood vessels are not oriented along the bone but rather radially (Fig. 16). Therefore, the cerclage loop has a minimal effect on periosteal blood supply.

When cerclage wires are tensioned and fixed with a knurl without special care there is often an elastic spring back producing a so-called” loose/lock stability”. The resulting micro movements at the interface between bone and wire induces bone surface resorption. (Fig. 17)

Conclusion:

Disregarding the myth of vascular strangulation of blood supply the cerclage offers help in demanding situations like periprosthetic fractures. It is important to avoid spring back of the connecting knurl to prevent induction biological loosening that results in gross instability.

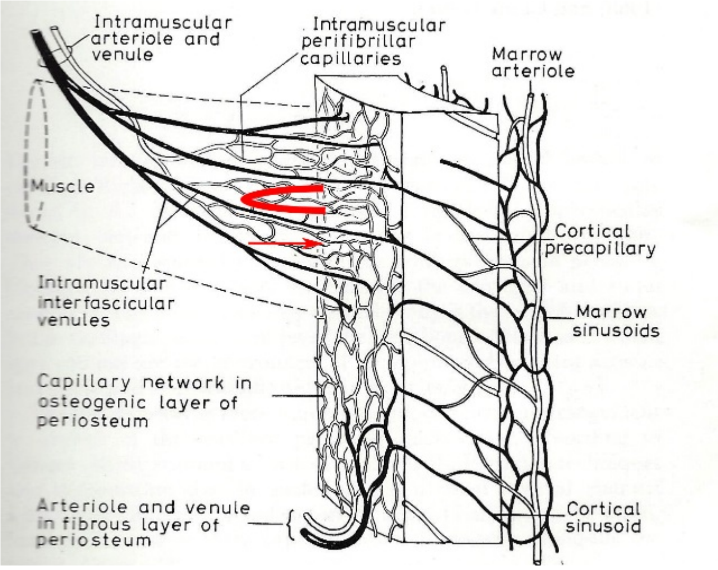

Fig. 16 *Radial orientation of periosteal blood vessels approaching bone along the muscle fibers (Brookes 1971). The red hemicircle indicates the position of the cerclage wire before tightening. The arrow indicates the expected displacement of the wire along the radially oriented blood vessels.*

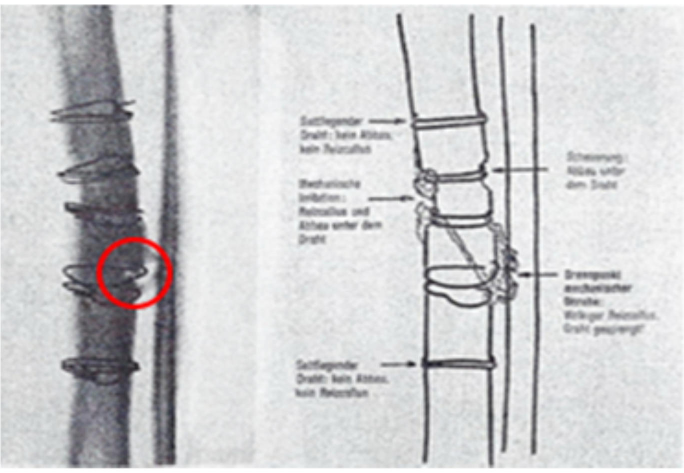

Fig. 17 *Bone resorption immediately deep to the cerclage wire (R. Leemann 1954)*

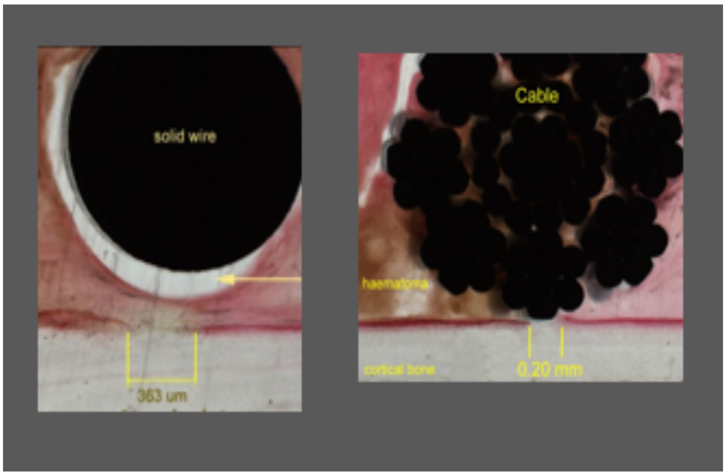

Fig. 18 *Histological demonstration of vascular damage for wire and cable cerclage (Perren et al. 2011)*

Cerclage application

Problems and Solutions, an overview

Preamble:

To take advantage offered by cerclages the technology of their application demands understanding, attention and skills. Understanding the rational of different applications and their effect on fracture healing is a prerequisite to success. Video

Problem:

Cerclages lend themselves best for long oblique and spiral fractures where they take advantage of a large lever arm. They are exceptionally capable when applied to spiral fractures with butterfly fragment at the location where all three fragments can be included within the loop. Under ideal circumstances this allows perfect reduction and anatomic contact of the three fragments in one action (Fig. 19 and 20) In other circumstances cerclages enable at least solid fragment contact by approximation rather than precise reduction. Atraumatic reduction, avoiding tissue damage, is realized using the "AO- cerclage passer.

Cerclages, may be used for reduction and may remain in place for fixation. Their contribution is restricted by limited strength either due to unwinding of the connecting knurl, or due to breakage of the wire. To take best advantage tensioning during application is important. Using cables (Fig. 22) instead of wires alleviates these disadvantages. The cable is stronger, more flexible and is able to reliably install and maintain tension. The limited strength of the cerclage loop does not allow its use as an exclusive (isolated) implant. In turn, when protected through additional load sharing splints such as the stem of a prosthesis, a plate or a nail, the cerclage offers valued help (Gauthier E, Perren SM. 1992). It is important to realize that a plaster cast cannot protect a cerclage, because the plaster cast is only loosely coupled to bone. Such coupling allows a range of bending deformation. The wire breaks before the cast function engages and would protect. The additional plaster cast adds inertia and with it loading. Some possible problems deserve attention:

- To increase the strength of the cerclage, instead of wires and cables, straps flat bands, made of metal or plastic (Fig. 23) were early on used. Their disadvantage of larger contact-damage to blood supply overweighs the improved strength
- The large blood vessels especially at distal femur or tibia may inadvertently be included within the loop and strangulated with deleterious effect. Special care is required when applying cerclages to non-reduced fractures and to bone segments with close relation of blood vessels and/or nerves ("danger segments").
- To increase the strength solid wires of larger diameter may be used. The disadvantage of such procedure is that when inadvertently bent at application the stiffer wire will not well adapt to the uneven surface of bone and result in contact points with high local stress.

Solution:

The attached video clip visualizes the major issues regarding procedures. Tissue damage at application may result due to stripping of the periosteum when the conventional technology for passing the wire around the bone and catching its tip results in extensive tissue displacement (Fig. 24). To avoid the latter a cerclage passer consisting of two instead of one semicircles (Fig. 25) that enables tissue-sparing application especially in the femur. Its basic concept evolved in the MIO group of the Technical Committee of the AO Foundation. This application is often less traumatizing than the application of free lag screws. To close the loop solidly under traction frequently a twisted knurl is applied. The wire is elastically deformable, therefore, when the knurl is applied by twisting, the knurl will exhibit a strong tendency to elastically spring back (Fig. 21). This results in loosening of the wire and in a "loose-lock" instability. Spring back may be avoided by twisting the knurl exceeding the elastic limit of the steel and plastically deform the knurl. Cutting off and bending down the knurl to lay flat against the surface are the next steps that may diminish or abolish the tension in the wire. Cutting is best done with a tightening movement. Bending down has a very different effect according to the direction of bending. The optimal direction of bending carries forward the twisting movement. Using crimped cables instead of twisted wires avoids the above-mentioned problems and are therefore an important advantage.

Conclusion:

Cerclage may be used as a temporary reduction tool or as efficient supplementary fixation. Safe use requires avoiding the pitfalls listed to take advantage of the possibilities offered.

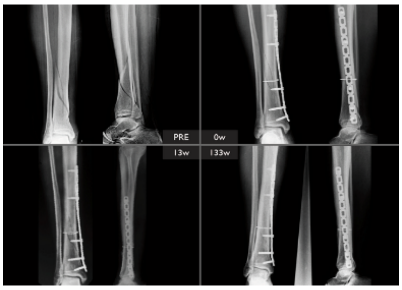

Fig. 19 *Use of Cerclage for reduction and fixation of shaft fractures. (extracted from the ICUC®app database)*

Fig. 20 *Use of cerclages for reduction and permanent stabilization of a periprosthetic fracture (extracted from the ICUC®app database)*

Fig. 21 *Spring back situation when the wire is deformed only elastically and not plastically. The glossy appearance of the wire indicates absence of plastic deformation.*

Fig. 22 *Cerclage using cable and crimp. Optimal traction and strength*

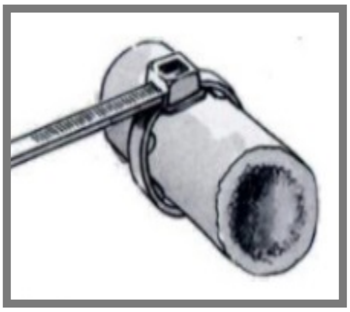

Fig. 23 *Strap used as cerclage. Due to tissue trauma the straps are today obsolete.*

Fig. 24 *The use of the conventional Demel instrument requires fairly large tissue displacement and with it tissue trauma to allow catching the wire at the tip of the instrument..*

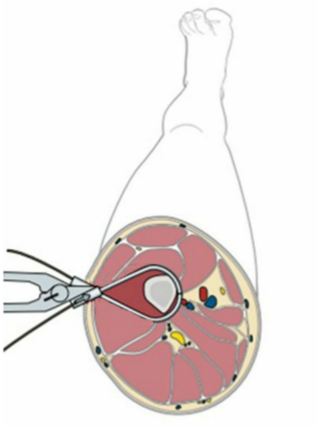

Fig. 25 *The AO wire passer produces minimal tissue trauma because the two elements of the instrument are applied sequentially and coupled thereafter.*

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