AN EXPERIMENTAL STUDY OF RING AVULSION INJURIES AND TWO PREVENTIVE DEVICES

Th. DUBERT, A. DIOP and P. VOELTZEL

From the Institut de la Main, Paris, France, Laboratoire de biomécanique de l'Ecole Nationale Supérieure des Arts et Métiers (ENSAM), Paris, France and Créations Haute Joaillerie, Paris, France

We have performed biomechanical experiments on fresh cadaveric fingers to test two modifications to normal rings which may prevent ring avulsion injuries. One of these modifications produced reliable protection against ring avulsion accidents and was undetectable. It thus does not reduce the symbolic value of a wedding ring.

Journal of Hand Surgery (British and European Volume, 2000) 25B: 5: 418–421

Pulling a ring from the finger may tear the skin, subcutaneous tissues, nerves and blood vessels. It may also avulse the entire finger, resulting in a complete degloving amputation. Since the first report of this injury (Crawford et al., 1952), the frequency of such accidents has been estimated at up to 200 or 350 cases per year in a population of 60 million (Bianchi et al., 1969; Carrol, 1974; Davalli and Zarotti, 1959; Holst-Nielsen, 1980), which represents 13 to 15% of all finger amputations. Major functional disability, cosmetic impairment and costly compensation insurance can result from these accidents, which usually occur in people of working age with large financial responsibilities (Burkhalter, 1985; Davalli and Zarotti, 1959; Foucher et al., 1986; Hung and Leung, 1989; Starovic et al., 1988; Tsai et al., 1984; Urbaniak et al., 1981; Van der Horst et al., 1989). The financial compensation for a complete ring finger amputation in European countries varies from 6% to 8% of total invalidity.

Education and prevention are necessary and are part of our duty as surgeons (Bevin and Chase, 1963; Bianchi et al., 1969; Carroll, 1974; Hovgaard et al., 1986; Weil et al., 1989). Several precautions are usually recommended, and the first is to remove the ring when involved in high-risk activities. However, the causes of injury are numerous (Table 1) and they can occur at home, at work, in recreation and even on the battlefield. Thus this advice in practice means abandoning the ring for the whole day (Carroll, 1974; Davalli and Zarotti, 1959; Flagg et al., 1977; Mitz, 1994; Scerri and Ratcliffe, 1994; Thompson et al., 1968). The second possible precaution is prophylactic slotting of the ring. This allows the ring to expand, allowing the finger to escape when excessive traction is applied. Although this modification has been advocated by many hand surgeons (Bevin and Chase, 1963; Carroll, 1974; Mitz, 1994; Weil et al., 1989), jewellers are reluctant to advise this procedure because it bothers their customers, damages the ring and reduces its symbolic value.

A third option is to weaken the structure of the ring. One technique has been suggested by Bianchi et al., (1969), and another by the United States Army (Varela, 1996) who suggest making two partial (75%) cuts through the inner surface of the ring at 4 o'clock and 8 o'clock. Although these procedures are interesting, their use is not supported by any objective biomechanical experiments, even though it is possible to reproduce a degloving injury in a cadaver finger by suddenly applying a 40 kg traction to a ring (Davalli and Zarotti, 1959).

As there is no commonly approved preventive device and no published data on the evaluation of skin resistance to ring avulsion injuries, we have carried out an experimental evaluation of the traction thresholds of fingers and have developed two devices to prevent ring avulsion injuries. This research has been performed in conjunction with the biomechanical laboratory of the Ecole Nationale Supérieure des Arts et Métiers (ENSAM).

MATERIAL AND METHODS

Forty fresh fingers on four female and four male cadaver hands with a mean age of 84 (range 75–90) years were used. The hands were obtained within 9 to 24 days of death and had not been frozen. All the fingers, but not the thumb, were tested after preliminary measurement (Table 2). Each finger was used several times, provided that it had not been injured. The forearms of each hand were mounted on a traction frame and were securely anchored to a custom-made iron box by passing two K-wires through the radius and ulna and holes in the box. The wires and the box were then firmly fixed together by pouring low melting point alloy (MCP 70) into the box. Load was applied to the rings in a distal direction, along the long axis of the finger, as in an accident. As we could not find a hook of sufficient strength, we passed a loop of steel cable around the ring and attached it to the traction machine with a braided low-stretch cable. We simulated different accident situations by performing tests at high and at very low speeds. All the experiments were recorded on slides and video.

For the high speed tests (76 tests, 5 cadavers, 17 fingers), the finger was placed horizontally and the braided low-stretch cable, which was passed around a pulley, joined the loop around the ring to a dead weight. This weight was dropped from 0.5 m and successive tests were performed on each finger with increasing loads until the skin or the ring broke. The last test in each

Table 1—Causes of ring avulsion injuries

Reported causes of accidents
Jumping from a moving vehicle
Catching on a pole or a fence post
Catching on a moving belt or other moving object
Catching under a manhole entrance
Catching in a roller press
Catching on a nail
Slipping off a ladder or a tree
Hanging up keys on a hook
Shutting a door
Catching in a door hinge
Catching on a shelf
Jumping into the water from a pier
Diving from a boat
Jumping over a rope
Attaching goalpost nets
Jamming in an anti-aircraft machine gun

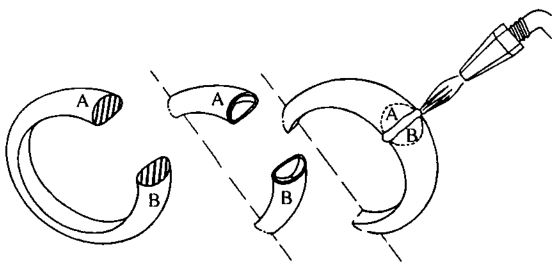

Fig 1 Group 2A ring manufacture. The ring is opened and the two cross-sections (A & B) are hollowed out by axial drilling, so as to leave only a thin peripheral wall. The continuity of the ring is then restored by soldering the hollowed ends together.

Table 2—Finger used in study

Finger	*Total number of tests*	*Severe cases*
Index finger ($n=11$)	33	5
Long finger ($n=11$)	33	5
Ring finger ($n=10$)	24	5
Little finger ($n=8$)	18	4

finger, which either caused the ring or the finger to break, was called the ultimate test. For each test, we recorded the dead weight (kg), the deformation and integrity of the ring and the presence and severity of any finger injury.

The low speed tests (32 tests, 6 cadavers, 23 fingers) were performed with the finger placed vertically. The braided cable was fixed to the load cell of an INSTRON 1185 traction-machine which ran at 0.01 m/min. The load-displacement curves were recorded until breakage of the skin or rupture of the ring. If the skin was injured, the force initiating the lesion (Fs) and the highest force (Fm), which corresponded to the top of the load–displacement curve or the resistance of the strongest tissue, were recorded.

All the rings were custom hand made from yellow gold, and had a "basket-handle" cross section. Two types of rings were tested. Group 1 rings were regular traditional wedding rings and underwent 56 tests (5 slow speed, 51 high speed — 10 of which were ultimate tests). Group 2 rings had a preventive weak point, so that they opened and let the finger escape with severe entrapment. This group was further divided into two sub-groups, one with (group 2A) and one without (group 2B) soldering of the device. Group 2A rings (Fig 1) underwent 19 tests at slow speed and 18 at high speed (of which 10 ultimate tests). During manufacture these rings were opened and their cross-section was hollowed out by axial drilling, so as to only leave a thin peripheral wall of gold on either side of the slit. The slit was then soldered close. The resistance of these rings depends on the strength of the remaining peripheral rim of gold (0.15–0.4 mm) and the type of solder used. Group 2B rings (Fig 2) underwent 8 low speed and 7 high speed tests (all were ultimate tests). During manufacture at least one hole was made through the cross-section of the ring. This hole was then plugged with a pin of gold which was press fixed, but not

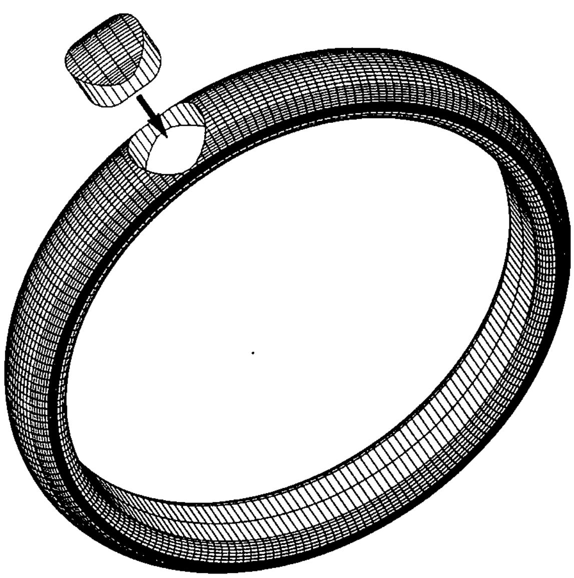

Fig 2 Group 2B ring. A hole is drilled through the ring, leaving thin bridges of gold at the periphery. The hole is then filled with gold pin which is not soldered into position and is masked by polishing.

soldered, in position. This ensured breakage of the ring at a fixed tensile stress, which can be accurately gauged as it depends on the remaining thickness of gold on either side of the pin whatever the direction of the hole relative to the ring cross-section.

The clinical classifications used for ring finger injuries (Beris et al., 1994; Kay, 1989; Nissenbaum, 1984; Sturznegger et al., 1988; Tsai et al., 1984; Urbaniak et al., 1981; Weil et al., 1989) are not suitable for evaluating preventive devices. We therefore developed a classification (Table 3) which separates benign (stages 0 and 1) from severe lesions (stages 2, 3 and 4).

RESULTS

A preliminary study confirmed that wedding rings that are completely cut across, producing a transverse slit, cannot cause an avulsion injury, whatever the loading rate.

Low speed tests were performed on 5 Group 1, 19 Group 2A and 8 Group 2B rings. Twenty-one fingers were not damaged as the rings opened (13 of the 19 Group 2A and all eight of the Group 2B rings) but one, finger sustained a superficial stage 1 lesion when a Group 2A did not open. The remaining ten fingers sustained severe lesions (two Grade 2, four Grade 3, four Grade 4), and only one of these rings opened (stage 2 injury in Group 2A ring). The other nine rings remained intact (all five Group 1 and four of the 19 Group 2A rings). For these severe injuries, the Fs ranged from 260 to 670 N (mean 461 N) and the Fm ranged from 330 to 741 N (mean 534 N). Complete amputation never occurred below 443 N. On the assumption that all the observations were independent, the probability of a severe lesion occuring below 351 N in these low speed tests is 14% (95% confidence interval = 0–28%).

In the high speed experiments, 28 ultimate tests were performed and these caused 14 stage 0 and five stage 1 injuries when the rings came away from the fingers. Nine fingers sustained severe lesions (three stage 2, four stage 3 and two stage 4) with weights ranging from 5 to 12 kg (mean 9:1 kg) which were dropped from a height of 0.5 m. No lesion occurred when the weight was less than 5 kg, and complete amputation never occurred below 10 kg. On the assumption that the observations were independent, the probability of a severe lesion at a force less than 5 kg is 2% (95% confidence intervals = 0–6%).

· The Group 1 (regular) rings caused eight severe and two benign (Stage 1) injuries in the ten high speed tests, and all these rings remained intact. The preventive system of the Group 2A rings (with soldering) opened before a severe lesion occurred in nine of the ten high speed tests. The seven Group 2B rings (without soldering) did not cause any severe lesions at high (or low) speed and always opened.

The differences between the three types of rings are highly significant (chi-square test: $P < 0.001$). Although the system used in Group 2B was hand-made, it appeared to provide good protection. Accurate measurement of the thickness of the gold wall around the blocked up hole will allow precise, reproducible gauging of the breaking point.

DISCUSSION

To our knowledge, this is the first experimental evaluation of ring avulsion injuries. The study was carried out to assess two experimental models for loading the rings at different speeds, to determine the traction thresholds beyond which severe lesions may occur, and to assess two preventive devices for inclusion in rings. The digital injuries observed in our experiments were identical to those observed in clinical cases. Our results suggest that the chance of a severe lesion occurring below 351 N in a low speed injury is 14% (CI = 0–29%). For high speed injuries, the estimated likelihood of a severe lesion below 5 kg is 2% (CI = 0–6%). The significance of these findings must be interpreted according to our experimental conditions. Firstly stage 2 injuries, which were classified as severe, would not compromise the viability of the finger. Secondarily, some fingers may have been weakened by previous traction tests, as each digit was used for an average of 4.5 high speed or 1.4 low speed tests. Finally the ages of the cadavers used in the study (75–90 years) meant that the mechanincal resistance of the skin was low. It had also lost its elasticity and extensibility

Table 3—Classification of experimental ring finger injuries

Stage	*Description*	*Appreciation*
Stage 0	No lesion	Benign lesions
Stage 1	Transdermal isolated skin shearing without skin avulsion	
Stage 2	Skin shearing with some avulsion No visible neurovascular injury	Severe lesions
Stage 3	Visible neurovascular injury Possible inadequate vascularization	
Stage 4	Complete amputation Sub-total amputation with only tendon continuity	

(Agache et al., 1980; Escoffier et al., 1989) because of epidermal thinning (Pereira et al., 1991) and flattening of the dermo-epidermal junction (Lavker et al., 1986) causing an increase in the visco-elastic component. The Young's modulus of skin doubles with age (Agache et al., 1980). We thus consider that our experimental conditions may have resulted in lower thresholds for injury than would be observed in the clinical setting.

The aim of our ring adaptations was to create a reproducible weak point which was invisible. We initially considered manufacturing several oblique or irregular slits in the ring which would be less visible, but then decided to mask the slit with a periphery of gold soldering (Group 2A rings). This modification made it almost impossible to differentiate between normal and modified rings, but the hollowing and soldering made it difficult to produce a completely reproducible weak point. It also altered the integrity of the uninterrupted ring. These drawbacks were resolved by the Group 2B ring which, with industrial manufacture, ensures breakage of the ring at a certain tensile stress. This is determined by precise measurement of the peripheral gold wall around the refilled hole. This modification is undetectable, as the chink around the pin is masked very well by polishing. Furthermore, the pin could be threaded so as to prevent it from falling out. With this system, the continuity of the ring in preserved, there is no reduction in the quantity or quality of the gold, and there is no opening or hollow that could alter the ring's symbolic value. This system can be adapted to the vast majority of rings, either during their initial fabrication or at a later time. Several preventive devices could be included in the same ring in special cases.

Acknowledgements

This work was performed in collaboration with the Anatomy laboratory of the Faculté de médecine des Saints-Pères in Paris (Professor J. P Lassau PhD). We would like to thank Joachim Magnier, from the Laboratory of bio-mechanics of ENSAM for his technical assistance, and Denis Bonnot for the statistical analysis.

Reference

Agache PG, Monneur C, Leveque JL, De Rigal J (1980). Mechanical properties and Young's modulus of human skin in vivo. Archives of Dermatological Research, 269: 221–232.

Beris AE, Soucacos PN, Malizos KN, Xenakis TA (1994) Microsurgical treatment of ring avulsion injuries Microsurgery, 15: 459–463

Bevin AG, Chase RA (1963). The management of ring avulsion injuries and associated conditions in the hand Plastic and Reconstructive Surgery, 32 391–400

Bianchi C, Cugola L, Lupia V (1969). Lesioni da anello alle dita della mani. Fracastro, 62. 63–71.

Burkhalter WE (1985). Ring avulsion injuries, care of amputated parts, replants, and revascularisation. Emergency Medicine Clinics of North America, 3: 365–369.

Carroll RE (1974) Ring injuries in the hand Clinical Orthopaedics and Related Research, 104: 175–182.

Crawford J, Horton CE, Oakey RS (1952). Avulsion of ring finger skin. Plastic and Reconstructive Surgery, 10: 46–49.

Davalli C. Zarotti F (1959). Lesione tipica da anello. Chirurgia Organi Morimento, 47· 411–421.

Escoffier C, de Rigal J, Rochefort A, Vasselet R, Lévêque JL, Agache PG (1989). Age-related mechanical properties of human skin: an in vivo study. Journal of Investigative Dermatology, 93: 35–37.

Flagg SV, Finseth FJ, Krizek TJ (1977). Ring avulsion injury. Plastic and Reconstructive Surgery, 59· 241–248

Foucher G, Citron N, Merle M, Dury M (1986). La revascularisation des arrachements digitaux par bagues Annales de Chirurgie de la Main, 5. 256–259.

Holst-Nielsen F (1980) Ringavulsioner. Ugeskrift for Laeger, 142: 2541–2542.

Hovgaard C. Gebuhr P, Klareskov B (1986). Ring avulsions. Ugeskrift for Laeger, 148 3310–3312.

Hung LK, Leung PC (1989). Salvage of the ring avulsed finger in heavy manual workers British Journal of Plastic Surgery, 42: 43–45.

Kay S, Werntz J, Wolff TW (1989). Ring avulsion injuries· classification and prognosis, Journal of Hand Surgery, 14A: 204–213.

Lavker RM, Zheng PS, Dong G (1986). Morphology of aged skin. Dermatologic Clinics, 4: 379–389

Mitz V (1994) Réimplantation des doigts d'alliance ou ring finger La Revue du Praticien, 44: 2456–2460.

Nissenbaum M (1984) Class IIA ring avulsion injuries: an absolute indication for microvascular repair. Journal of Hand Surgery, 9A· 810–815.

Pereira JM, Mansour JM, Davis BR (1991). The effects of layer properties on shear disturbance propagation in skin Journal of Biomechanical Engineering, 113: 30–35.

Scerri GV, Ratcliffe RJ (1994). The goalkeeper's fear of the nets. Journal of Hand Surgery, 19B. 459–460.

Starovic B, Rajacic N, Ninkovic M (1988). Povrede prstiju sake prstenom. Medicinski Arhiv, 42: 99–104

Sturzenegger M, Büchler U, Frey HP (1988) Ringavulsionsverletzungen: verfeinerte Indikationsstellung zur Replantation. Handchirurgie, 20: 255–258

Thompson LK, Posch JL, Lie KK (1968). Ring injuries. Plastic and Reconstructive Surgery, 42: 148–151.

Tsai TM, Manstein C, DuBou R, et al. (1984). Primary microsurgical repair of ring avulsion amputation injuries. Journal of Hand Surgery, 9A: 68–72.

Urbaniak JR, Evans JP, Bright DS (1981) Microvascular management of ring avulsion injuries. Journal of Hand Surgery, 6 25–30

van der Horst CMAM, Hovius SER, van der Meulen JC (1989). Results of treatment of 48 ring avulsion injuries. Annals of Plastic Surgery, 22: 9–13.

Varela CD (1996). Case report: ring avulsion injuries in a field environment Military Medicine, 161: 308–310.

Weil DJ, Wood VE, Fryckman GK (1989) A new class of ring injuries. Journal of Hand Surgery, 14A. 662–664.

Received 27 March 2000
Accepted after revision 12 June 2000
Dr T Dubert, Institut de la Main, 6 square Juvenet, Paris, France
Tel + +33 1 6 4434390, Fax: + +33 1 6 4434498, E-mail: sosmain@club-internet fr

DOI 10.1054/jhsb 2000.0464, available online at http.//www idealibrary com on IDEAL®