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INFECTIONS AND BIOABSORBABLE IMPLANTS IN ORTHOPAEDIC AND TRAUMA SURGERY – WITH SPECIAL REFERENCE TO THE TREATMENT OF ANKLE FRACTURES

A clinical study by

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Academic dissertation

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ABSTRACT

Infections comprise the most devastating complications associated with internal fracture or ostetomy fixation. Implants used in the fixation of bone make tissue more vulnerable to bacterial colonization by enabling bacterial adhesion to the surfaces and also by hampering the immunological responses to bacteria. However, there is some theoretical and experimental data that these responses could be adjusted by using different implant materials.

The bioabsorbable osteosynthesis devices have been in clinical use since 1984. Their indications now include numerous cancellous bone fractures and osteotomies as well as some soft-tissue injuries. Their degrading products have been shown under *in vitro* conditions to be bacteriostatic or even bacteriocidic. There are no previous clinical studies testing these effects under a clinical setting.

The infection rates among 2114 patients treated with bioabsorbable osteosynthesis devices were investigated. Depending on the bioabsorbable material used, the infection rates varied from 0,7 per cent (SR-PLLA) to 6,5 per cent (SR-PGA and SR-PLLA together). In a comparison with metallic osteosynthesis devices, the files of 3111 ankle fracture patients were studied. There was no significant difference between the infection rates of the bioabsorbable fixation group (3,2 per cent) and metallic fixation group (4,1 per cent). Due to the limitations in the use of bioabsorbable implants (e.g. unavailability of plate-fixation during the first few years), the fracture patterns differed slightly between the groups.

The effect of bioabsorbable implant volume on wound infections was investigated in a series of 846 patients. There was a significant positive correlation between the incidence of infection and the implant volume when non-stained SR-PGA or SR-PLLA implants were used. In a paired setting of 56 ankle fracture patients (28 with wound infections and 28 controls) the raising of the implant-bone volume ratio correlated with the rising incidence of infection on the medial side, but no correlation existed on the lateral side.

The most popular method for ankle fracture fixation is that described by the AO-ASIF group, using devices made of steel. In the present study, the use of a bioabsorbable SR-PLLA syndesmosis screw in conjunction with metallic fracture fixation was investigated. With a minimum of a one-year follow-up, there was no difference in the clinical or radiological parameters assessed, making the bioabsorbable SR-PLLA syndesmosis screw without a need for removal operation the method of choice for syndesmosis transfixation.

LIST OF ORIGINAL PUBLICATIONS

I. Sinisaari I, Pätiälä H, Böstman O, Mäkelä EA, Hirvensalo E, Partio EK, Törmälä P, Rokkanen P. Wound infections associated with absorbable or metallic devices used in the fixation of fractures, arthrodeses and osteotomies. Eur J Orthop Surg Traumatol 5: 41-43, 1995

II. Sinisaari I, Pätiälä H, Böstman O, Mäkelä EA, Hirvensalo E, Partio EK, Törmälä P, Rokkanen P. Metallic or absorbable implants for ankle fractures. A comparative study of infections in 3111 cases. Acta Orthop Scand 67: 16-18, 1996

III. Sinisaari I, Pätiälä H, Böstman O, Mäkelä EA, Partio EK, Hirvensalo E, Törmälä P, Rokkanen P. Effect of totally absorbable implant volume on wound infection rate: Study of 2500 operated fractures, osteotomies, and ligament injuries. J Orthop Sci 2: 88-92, 1997

IV. Sinisaari I, Pätiälä H, Viljanen J, Kinnunen J, Kataja M, Rokkanen P. The effect of implant-bone volume ratio on the post-operative wound infections. A clinical study of 934 ankle fracture patients operated on with bioabsorbable polyglycolide implants. Submitted, Clin Orthop

V. Sinisaari IP, Lüthje PM, Mikkonen RHM. Ruptured tibio-fibular syndesmosis: comparison study of metallic to bioabsorbable fixation. Foot Ankle Int 22: 744-748, 2002

The afore-mentioned papers will be referred to in the text by their Roman numerals.

ABBREVIATIONS

Acetyl-Coa	acetyl co-enzyme A
a.m.	*ad modum* (“described by”)
AO-ASIF	Arbeitsgemeinshaft für Osteosythesefragen – Association for the Study of Internal Fixation
CT	computed tomography
D-2-HDH	D-2-hydroxyacid dehydrogenase
e.g.	*exempli gratia* (“for example”)
i.e.	*id est* (“that is”)
LDH	lactate dehydrogenase
Mpa	mega Pascal (10^6 Newton/m^2)
MW	molecular weight
PDH	pyruvate dehydrogenase
PDS	polydioxanone
PGA	polyglycolic acid or polyglycolide
PLA	polylactic acid or polylactide
PLLA	poly-L-lactic acid or poly-L-lactide
SD	standard deviation
SR	self-reinforced

1 INTRODUCTION

Exact open reduction and internal fixation have been used for decades for gaining the optimum result in the treatment of displaced fractures (Rüedi 2000). Experiments with implants made of various available materials (e.g. bone from animals) were performed during the late 19th and early 20th centuries, but soon it became evident that these xenografts do not possess sufficient tissue compatibility for fixation purposes. With the development of metallurgic knowledge, it was possible to prepare implants made of different alloys (mainly steel) strong enough for fixation of unstable fractures. However, these implant materials had certain disadvantages: stress-protection with a risk of refractures (Paavolainen et al. 1978), corrosion (Merritt and Brown 1985), allergy (Hallab et al. 2001), late migration (Rai et al. 1991), artifacts to radiological examinations, and subjective discomfort due to sense of bulkiness. For these reasons, removal of the implants is often recommended (Rüedi 2000) and patients have been shown to benefit from it (Jacobsen et al. 1994).

Biodegradable implants were developed to avoid the above-mentioned problems (Rokkanen et al. 2000). After the initial start in 1984 (Rokkanen et al. 1985), their indications have now expanded to cover most cancellous bone fractures and osteotomies as well as ligament injuries, and presently implants are available in various shapes.

During the 1980's, simultaneously with the development of the knowledge on bioabsorbable materials, the pathophysiology of foreign-body infections was avidly investigated (Gristina and Costerton 1985). It was found that bacteria were able to adhere to the surfaces of implants and that the material of the implant may also have some effect on the bacterial adherence. The more concomitant findings proving that the degradation products of the polyglycolide and polylactide used for bioabsorbable implants may have some bacteriostatic or even bactericidal activity (Mouzas and Yeadon 1975, Stillman et al. 1980) established the theoretical basis for the present study.

2 REVIEW OF THE LITERATURE

2.1 Pathophysiological mechanisms involved in implant-related infections

Internal osteosynthesis implants as such have been shown to increase the risk of infection in an experimental setting (Merritt 1988, Chang and Merritt 1994, Melcher et al. 1994, Arens et al. 1996a, Arens et al. 1999, Merritt et al. 1999). The mechanisms by which implants modify the risk of infection include their effect on bacterial adhesion, tissue integration, and immunomodulation. The mechanisms involved will be briefly reviewed in the following chapters.

2.1.1 Mechanisms of bacterial adhesion to biomaterial surfaces

Bacterial adhesion to the implant surface is the first step in the development of an implant-related infection. The adhesion occurs in a two-step manner (Gristina 1994, An and Friedman 1998a): the first step is instantaneous and reversible involving physicochemical interactions (van der Waals forces, gravitational forces, hydrophobic interactions) between the implant surface and the bacteria, making way for the second, often irreversible, step with a formation of molecular-level (covalent or hydrogen binding) interactions. In more evolved bacteria these may still proceed to a more specific bacterial receptor to surface ligand interactions. Gristina has described these first events as “race for surface” where the “empty” implant surface is first colonized either by the organism’s own cells or bacteria after which the equilibrium is very hard to change (Gristina 1987). Different bacterial species and strains adhere differently to material surfaces. This is due to differing physicochemical properties between the surfaces and bacterial species and strains (Hogt et al. 1985, Hogt et al. 1986, Veenstra et al. 1996, Heilmann et al. 1997).

The primary surface adhesion is followed by a phase of bacterial accumulation onto the implant (von Eiff et al. 2002). The most marked phenomenon of this phase is the ability of some bacteria to produce an extra-cellular mucopolysaccharide biofilm, “slime”, and cover the colonies. This slime enhances bacterial nutrition, interferes with the phagocytosis and antibody function of the host, and promotes further bacterial aggregation (Gristina 1987). The most prominent bacteria capable of producing such mucopolysac-

caride slime are the coagulase negative staphylococci, of which the most thoroughly examined and clinically relevant is *Staphylococcus epidermidis*. It has been known for long that the slime-producing strains of *S. epidermidis* cause more frequently foreign-body infections than the non-producing sister strains (Christensen et al. 1983, Jansen et al. 1989, Galdbart et al. 2000). Besides affecting the host defence mechanisms, the extra-cellular slime also provides a physicochemical barrier against both systemic and implant-released antibiotic therapy, making infections difficult to treat without hardware removal (Chang and Merritt 1991, Stewart 2002, Vuong and Otto 2002).

2.1.2 Implant-related factors on bacterial adherence

There are numerous implant-dependent factors affecting the bacterial adherence to the surface. These include chemical composition, surface roughness and configuration, and possible surface coating (An and Friedman 1998b). The chemical composition of the implant may cause predominance of certain bacteria in adherence to the surface. In classical studies by Gristina and co-workers (Gristina and Costerton 1985, Gristina et al. 1985) it was shown that, due to the binding properties of bacterial capsules and slime to the implant materials, *S. epidermidis* is the most frequent finding in polymeric implant-associated infections, whereas *S. aureus* is mostly found on metallic surfaces. Later Arens et al. (1996b) have found significant differences in bacterial adherence depending on the metal used with titanium being generally less susceptible to bacterial colonization compared to steel.

An intriguing question is whether bioabsorbable polymeric implants are capable of making the host less susceptible to bacterial invasion, since, theoretically, the implant does not provide a stable surface for the bacteria to adhere. Petas et al. (1998) have investigated in vitro bacterial adherence to urological stents made of polyglycolic or polylactic acid. They found that urological flora adhered to these bioabsorbable surfaces. One experimental study has indirectly tested this hypothesis in conjunction with bone-associated infection (Mainil-Varlet et al. 2001): poly-L-lactic acid and poly-L/DL-lactic acid rods were implanted in the rabbit tibiae medullary cavity previuosly incubated with different inoculum of *S. aureus* in an effort to quantify the bacteriostatic effect of the degrading products

of the implant. After removal the bacteria could be cultured from the rod surfaces. It has to be pointed out, however, that the rods were implanted into the medullary canal with pre-adhered bacteria thus giving the bacteria a head start in “the race for the surface”. In the current literature, there are no clinical studies on this subject.

Increasing the surface roughness and making the surface configuration more complex will make the implant more susceptible to bacterial colonization. Under *in vitro* conditions, polymeric biliary stents with irregular surfaces allow bacterial adhesion and biofilm accumulation that cause stent occlusion, while such problems are not noted in stents with ultrasmooth surface coating (McAllister et al. 1993). Under similar *in vitro* conditions, *S. epidermidis* was shown by scanning electron microscopy to grow preferably in surface irregularities of metallic implants (Oga et al. 1993). In intramedullary cylinders implanted in the rabbit femur a 40 times higher bacterial concentration was required to cause a clinical infection in polished cobalt-chromium implants compared to porous-coated implants; for similar implants made of titanium the corresponding difference in the bacterial concentration was 2,5 times higher (Cordero et al. 1994, Cordero et al. 1996). Similar results have been received with non-absorbing sutures implanted in the rat subcutis with multifilament sutures found to be significantly more susceptible to infection than monofilament sutures (Merritt et al. 1999). Merritt et al. (1979) had already earlier shown that bacteria tend to colonise on porous surfaces more easily immediately after implantation, whereas later the dense surfaces are more inclined to bacterial invasion. The authors explain this by tissue integration which, after occurring on the porous surface, makes the surface highly resistant to bacterial invasion, while fibrous tissue coating over dense surfaces does not provide such a shelter.

2.1.3 Immunomodulation caused by foreign-body materials

In addition to bacterial and implant properties, the modified immune response of the host plays a key role in the aetiological process of foreign-body infection. All implanted devices cause a foreign-body reaction, the severity of which is dependent on numerous factors: tissue damage caused by trauma and surgery, material of the implant (Merritt and Rodrigo 1996, Böstman and Pihlajamäki 2000, Hallab et al. 2001), and size and chemical composition of the debris particles present (Shanbhag et al. 1994). It is currently thought that these inadvertent activations of the macrophage system may hamper the bacteria phagocytosing functions of the immune response.

Besides activating the macrophages, also other phagocytosing cells may be activated by foreign-bodies: PGA implanted in the rat peritoneal cavity has been shown to activate polymorphonuclear leukocytes (Devereux et al. 1991) and, in an *in vitro* setting, lymphocytes (Santavirta et al. 1990). Polylactic acid elicits early reaction in macrophages and giant cells, while other cell lines seem to be inactive (Majola et al. 1991, Hara et al. 1994). Different metal alloys also modify the superoxide production of polymorphonuclear leukocytes with steel particles causing the greatest decrease (Pascual et al. 1992). The influence of these phenomena on individual bacterial immunity is still under investigation. Intensive research is being carried on to understand these responses and to modify them so that the likelihood of a foreign-body infection would be diminished (Gristina 1994, An and Friedman 1998b).

2.2 Bioabsorbable fracture fixation

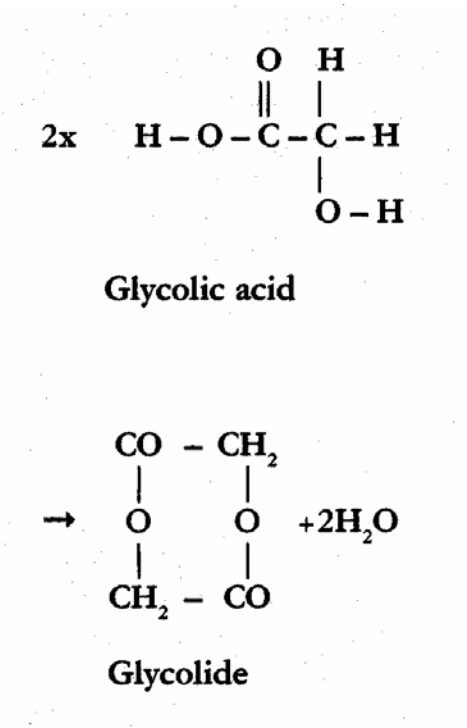
Poly-alpha-hydroxy acids have been under research for development of bioabsorbable surgical devices for decades (Kulkarni et al. 1966, Schmitt and Polistina 1969, Kulkarni et al. 1971, Vert et al. 1981, Vainionpää 1987, Voutilainen 2002). Due to their mechanical strength, polyglycolic acid and polylactic acid are the most appropriate materials for bioabsorbable orthopaedic implants.

2.2.1 Polyglycolides

2.2.1.1 Chemical properties

Polyglycolic acid (polyglycolide, PGA) with a high molecular weight suitable for surgical device production was first synthesized by Higgins (1954). A high-molecular weight PGA is a hard, crystalline polymer. When used for orthopaedic implants, its molecular weight ranges from 20 000 to 145 000 (Törmälä et al. 1998). PGA is synthesized from glycolic acid by dehydrating it to glycolide after which the synthesization is accomplished by ring opening polymerization (Schmitt and Polistina 1969) (Fig. 2.1).

Figure 2.1. Synthesis of polyglycolide from glycolic acid



Ring-opening polymerization →

$(CH_2CO\text{-}O\text{-}CH_2CO\text{-}O)_n$-

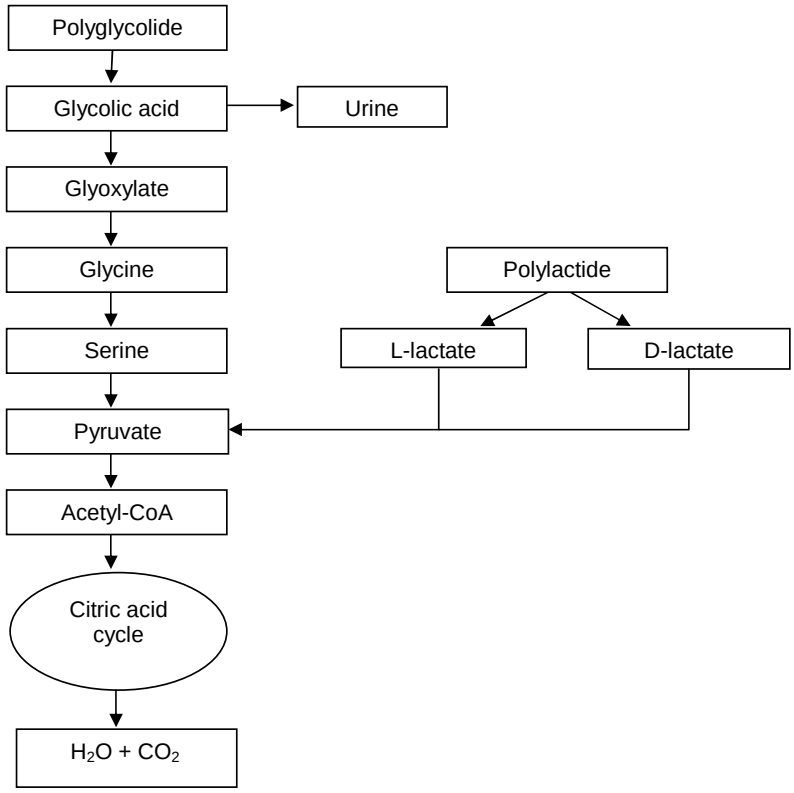
Polyglycolic acid or polyglycolide

The biodegradation of PGA proceeds through hydrolysis, the reactions of which are in vivo enhanced by enzymatic activity (Williams 1981). The degrading process enhancing enzymes transform degradation products into glycine which can be used in the proteine synthesis, or pyruvate, which, in turn, may enter into the mitochondrial citric acid cycle (Frazza and Schmitt 1971, Williams 1981, Hollinger 1983, Hollinger and Battistone 1986). The end-products are thus carbon dioxide and water, with a small portion of glycolic acid excreted to urine (Fig. 2.2).

2.2.1.2 Biodegradation

The degradation time is affected by the tissue of implantation, the molecular weight, the purity and the chrystallinity of PGA used, and by the size and shape of the implant. The strength retention in bone tissue takes from four to eight weeks to reach the level of that of cancellous bone (Vasenius et al. 1990), with complete degradation in bone with disappearance of the PGA by 36 weeks (Böstman et al. 1992b). However, a large implant size and the use of high-molecular weight PGA prolong the degradation process (Hollinger and Battistone 1986, Törmälä et al. 1991, Törmälä 1992).

Figure 2.2. Biodegradation of polyglycolide and polylactide



2.2.1.3 Biocompatibility and tissue responses

Under in vitro conditions, PGA is an immunologically inert substance, provoking only slight lymphocyte activation (Santavirta et al. 1990). In experimental rabbit studies the foreign-body reactions associated with PGA implants in cancellous bone have been at their peak during a period of three to 12 weeks from implantation. The reactions are giant cells adhering to the implant surface from three to six weeks (Päivärinta et al. 1993) after which macrophages and polymorphonuclear leukocytes are most numerous at 12 weeks (Böstman et al. 1992, Böstman et al. 1992a).

Under a clinical setting, polyglycolide implants have shown transient inflammatory responses with fluid accumulation and occasional sinus formation. The highest incidence of tissue reactions, 25 per cent or five out of 20 patients, was noted in operations of scaphoid nonunions (Pelto-Vasenius et al. 1995). In fresh fractures, the highest incidence has been seen in patients operated on for ankle fractures with PGA implants containing aromatic quinone dye (19 reactions among 105 patients, 18 per cent) (Böstman et al. 1992c). Generally the incidence of tissue reactions has been around five per cent of the patients in most of the fresh fractures treated: ankle fractures with non-stained implants (Hirvensalo 1989, Böstman et al. 1992c), radial head fractures (Hirvensalo et al. 1990), distal radial fractures (Casteleyn et al. 1992), and olecranon fractures (Juutilainen et al. 1995). The lowest incidence of tissue reactions noted to date has been three per cent of the patients (two out of 60 patients) in chevron osteotomies for hallux valgus (Hirvensalo et al. 1991). In a large series of 2037 patients operated on with implants made of self-reinforced PGA only, clinically relevant foreing-body reactions were found in 5,3 per cent (107 reactions) of the patients (Böstman and Pihlajamäki 2000).

2.2.1.4 Mechanical properties and clinical applications

Osteosynthesis implants made of PGA can be produced by several different methods (e.g. compression moulding, injection moulding, machining) (Vert et al. 1981). However, all the implants investigated in the present study were manufactured with the self-reinforcing technique (Törmälä et al. 1988). In this method, fibres of PGA are sintered together at a high temperature and pressure producing a construction where the matrix and reinforcing fibres are of the same material.

Initially, these implants show ultra-high bending (up to 405 MPa) and shear (up to 250 MPa) strengths (Törmälä et al. 1991) with relatively rapid decrease to the level of that of cancellous bone in four to eight weeks (Vasenius et al. 1990). Due to the rapid decrease in the strength of the implant, they are not suitable for cortical bone fixation (Vainionpää et al. 1986). However, SR-PGA implants have been investigated in many cancellous bone fractures and osteotomies, showing sufficient strength properties for fixation of ankle fractures (Rokkanen et al. 1985, Böstman et al. 1989a, Hirvensalo 1989), distal humeral physeal fractures (Böstman et al. 1989b, Mäkelä et al. 1992), radial head fractures (Hirvensalo et al. 1990), distal radial fractures (Casteleyn et al. 1992), hand fractures (Kumta et al. 1992), olecranon fractures (Juutilainen et al. 1995), patellar fractures (Juutilainen et al. 1995), distal femoral epiphyseal fractures (Partio et al. 1997), tibial condylar fractures (Kankare 1997), talar fractures (Kankare and Rokkanen 1998), and calcaneal fractures (Kankare 1998). However, due to the risk of tissue reactions the use of SR-PGA implants has declined during the recent years in favour of implants made of polylactide.

2.2.2 Polylactides

2.2.2.1 Chemical properties

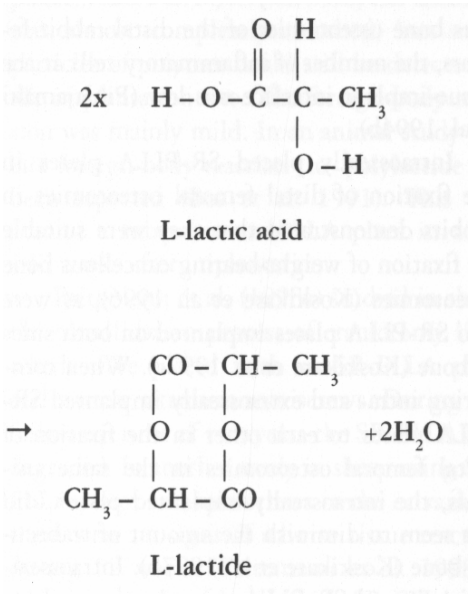
The lactic acid molecule is asymmetric. L-lactic acid is active in anaerobic metabolism of living cells. The polymerised form used in the manufacture of surgical devices was first presented by Schneider (1955).

Due to asymmetry, lactic acid has two enantiomeric forms: L and D. They are two optically active stereoisomers which have opposite configurational structures but similar intrinsic chemical properties.

Thus, when the dimere of lactide is formed out of two lactic acid molecules, there are four possible diastereoisomers (Vert et al. 1984).

The polylactide with a molecular weight sufficient for manufacturing implants is most efficiently produced by ring-opening polymerization of cyclic di-esters (Lowe 1954, Hyon et al. 1997) (Fig. 2.3). When its molecular weight raises higher than 100 000, poly-L-lactide (PLLA) obtains a highly crystalline structure (Vert et al. 1981, Hollinger and Battistone 1986, Törmälä et al. 1998).

Figure 2.3. Synthesis of PLLA from L-lactic acid



Ring-opening polymerization →

$[CH(CH_3)CO\text{-}O\text{-}CH(CH_3)CO\text{-}O]_n$ –

Polylactic acid (PLA) or polylactide

2.2.2.2 Biodegradation

Polylactide, as polyglycolide, is mainly degraded by hydrolysis, with slight contribution from unspecific enzymatic activity (Kulkarni et al. 1966, Miller et al. 1977, Williams 1981, Hollinger and Battistone 1986). After undergoing hydrolytic de-esterification the lactic acid molecules are transformed into pyruvate by lactate dehydrogenase. Pyruvate is then entered into the citric acid cycle and transformed into carbon dioxide and water with energy extracted (Fig. 2.2 on page 18). The final extrution from body occurs thus mainly by lungs, with small portions going into urine and faeces.

The degradation time of PLLA is considerably longer than that of PGA and extremely variable (Voutilainen 2002). It is affected, not only by the site of implantation and the size and shape of the implant, but also by factors associated with the polylactide raw material used: stereoisometric proportions (Kulkarni et al. 1971, Vert et al. 1984), purity (Nakamura et al. 1989), molecular weight (Vert et al. 1981), crystallinity (Vert et al. 1984), surface morphology (Hollinger and Battistone 1986, Lam et al. 1995), and manufacturing and sterilising methods (Gogolewski and Mainil-Varlet 1997, Mainil-Varlet et al. 1997a, Mainil-Varlet et al. 1997b, Törmälä et al. 1998). Of the SR-PLLA implants used in the present study, Voutilainen and associates (Voutilainen et al. 2002) have found remnants of the implants from ankle fracture patients more than nine years postoperatively. The remnants presented themselves as asymptomatic palpable masses over medial malleoli. When removed, they showed inflammatory cellular mass with fibres of PLLA.

2.2.2.3 Biocompatibility and tissue responses

There are no in vitro studies investigating the cytological immune response of PLA. In experimental studies the biocompatibility of PLA has been generally favourable, and the arrangements have been versatile: PLA has been implanted in the maxillofacial area as extra-osseous plates (Cutright and Hunsuck 1972, Bos et al. 1989, Rozema et al. 1990, Bos et al. 1991, Suuronen et al. 1992, Suuronen et al. 1997, Suuronen et al. 1998) and intraosseal screws (Suuronen et al. 1994, Kallela et al. 1999), as intra-osseal plates in the rat femur (Koskikare et al. 1996), and in the rat and sheep as intraosseal rods (Majola et al. 1991, Manninen and Pohjonen 1993), screws (Manninen et al.

1992), and plugs (Pihlajamäki et al. 1994b, Pihlajamäki et al. 1994c). The cellular response has been that of an initial fibrous capsulation thinning up to six months with mild macrophage and lymphocyte activation (Gogolewski et al. 1993, Pihlajamäki et al. 1994b, Kallela et al. 1999). With long degrading times there will be a late tissue response constituting cellularity changes years after the implantation. These have been investigated intraosseously in the rabbit distal femora (Matsusue et al. 1995, Saikku-Bäckström et al. 2001) and in the femoral neck of sheep (Jukkala-Partio et al. 2001, Jukkala-Partio et al. 2002). In all of these studies, the complete disappearence of the polymeric material took more than three years and was completed by seven years. The late degradation process occurred in the presence of a few macrophages without other cell line responses. Under experimental setting the implant channel has been shown to be replaced by bone tissue (Jukkala-Partio et al. 2002), but in long-term follow-up ankle fracture patients operated on for non-resorbed screw heads the screw channels could be visualized containing loose connective tissue (Voutilainen et al. 2002).

Clinically significant foreign-body reactions are far more rarely seen with PLA than with PGA.

In short-term studies, the biocompatibility has been acceptable with no clinical manifestations of foreign-body reactions (Partio et al. 1992a, Partio et al. 1992b, Pihlajamäki et al. 1992, Böstman et al. 1995, Burns 1995, Juutilainen et al. 1995, Matsusue et al. 1996, Barca and Busa 1997a, Barca and Busa 1997b, Tuompo et al. 1997, Tuompo et al. 1999a, Tuompo et al. 1999b).

Clinically manifest reactions have been reported from extra-osseous plates used for zygomatic fracture fixation three and five years postoperatively (Bergsma et al. 1993, Bergsma et al. 1995). The only reported case of tissue reaction after intraosseal use of a PLA implant is that of a bimalleolar fracture patient who developed a macrophage and giant cell-mediated reaction at the site of the lateral malleolar screw head more than four years post-operatively (Böstman and Pihlajamäki 1998). The countersink was used, but the screw head had not been cut to the bone surface.

2.2.2.4 Mechanical properties and clinical applications

By self-reinforcing manufacturing methods, the initial bending strength of SR-PLLA screws and rods may rise up to 240 MPa and the shear strength up to 156 MPa (Törmälä et al. 1987, Pohjonen and Törmälä 1996), which is sufficient for cancellous bone fixation.

Clinical studies on SR-PLLA implants have been conducted on numerous indications of which ankle fractures have been one of the most frequently treated traumatic disorders. In ankle fracture patients SR-PLLA implants have been used predominantly on the medial malleolus. Expansion plugs have been used in 22 patients with untroubled results (Pihlajamäki et al. 1994a). Bucholz et al. (1994) compared the results of 155 consecutive patients with ankle fractures with medial malleolar involvement. The functional results between SR-PLLA and metallic screw fixation were similar. In a series of 51 patients with SR-PLLA implants used in all three malleoli, there was one lateral malleolar non-union (Böstman et al. 1995). In a recent long-term study of 16 ankle fracture patients operated on with implants made of SR-PLLA, the patients were examined after a mean follow-up of 9.6 years (Voutilainen et al. 2002). Bony union was found in all patients, and good or excellent clinical results in all but one patient. Of an elective series in the ankle area, Partio fused a total of 12 ankles with bioabsorbable screws after post-traumatic arthrosis had occurred (Partio et al. 1992b). There were two patients with implants made of SR-PLLA only, and they reached bony union in six and eight weeks.

Tuompo and co-workers performed a total of 28 proximal tibial osteotomy or fracture fixations with bioabsorbable implants (11 with SR-PLLA implants only) (Tuompo et al. 1999a). They noted four radiological redisplacements without need for re-operation and concluded that bioabsorbable implants can be used with good to moderate results. They have also used bioabsorbable fixation in the treatment of osteocondritis dissecans in the knee, with good to excellent results in 19 out of 24 patients (Tuompo et al. 1997).

In a series of 35 patients, a total of 21 patients with patellar or olecranon fractures were treated with bioabsorbable fixation and 14 patients with metallic fixation (Juutilainen et al. 1995). The results were comparable.

Barca and Busa performed 25 Akin osteotomies fixed with PLLA staples (Barca and Busa 1997a). All of their osteotomies healed uneventfully. They also investigated the use of the PLLA screw in Austin-chevron osteotomies (Barca and Busa 1997b). In a total of 35 ostetomies they had 34 unions and one metatarsal head avascular necrosis. They suggested that the implant material had no effect on that complication.

An SR-PLLA expansion plug was used for fixation in a modified Bristow-Latarjet procedure for recurrent anterior humeral dislocations (Pihlajamäki et al. 1994d). Out of 33 patients operated on, 18 randomly selected patients were examined with a minimum follow-up of six months. Fifteen bony unions were noted, with no redislocations.

Juutilainen and Pätiälä (1995) described a series of 53 patients with rheumatoid arthritis necessitating arthrodesis (mainly wrist or hand). They reached bony union in all but two patients, both of whom had the talocrural joint operated.

In addition to osteosynthesis applications, SR-PLLA implants have been used for ligament injuries, meniscal refixations, shoulder joint capsule fixations, and, recently, in interposition arthroplasties in metacarpophalangeal and the first metatarsophalangeal joints.

2.3 Ankle fractures

2.3.1 Epidemiology of ankle fractures

There are numerous reports in the literature about the incidence and epidemiology of ankle fractures but most of them are institution-based. Well documented population-based reports give relatively similar incidences for ankle fractures: In the Malmö area in southern Sweden there were 739 ankle fractures during the three-year study period of 1980-1982, equalling 107 fractures per 100000 inhabitants per year (Bengner et al. 1986, Bauer et al. 1987). The raise from the comparison period of 1950-1952 was approximately two-fold overall and most prominent in the elderly women. During a similar time period (1979-1982) the annual incidence of ankle fractures in Rochester, Minnesota in the north-east of the USA was substantially higher, 187 fractures per 100000 inhabitants (Daly et al. 1987). This may partially be explained by different inclusion criteria, since the American study included all recorded diaphyseal fibular fractures and lateral malleolar avulsion fractures. During their study period 27 per cent of the fractures were treated with open reduction and internal fixation. Osteoporotic ankle fractures occurring in the patients over 60 years of age have been studied nation-wide in Finland (Kannus et al. 1996). The incidence of such fractures in 1994 was 130 fractures per 100000 inhabitants per year, whereas the corresponding incidence in the year 1970 had been 57. The most recent reported population-based study on ankle fracture incidence comes from Aalborg, Denmark (Jensen et al. 1998). In a city of approximately 200000 inhabitants the one-year incidence of ankle fractures was 107 cases per 100000 inhabitants during the one-year study period of 1994-1995. Forty-two per cent of the fractures (91/212) needed operative treatment. The distribution of different ankle fracture types has been described in a series of 1500 consecutive ankle fractures admitted to the Edinburgh Orthopedic Trauma Unit in Scotland, UK (Court-Brown et al. 1998). The fractures were classified according to the AO system. Seventy per cent of the ankle fracture patients had a lateral malleolar fracture, approximately one fourth had a bimalleolar fracture, and seven per cent of the patients had a trimalleolar fracture.

The incidence of ankle fractures seems to be rising in the western societies due to more osteoporotic fractures occurring in older patients. This will make great demands on the health care systems in these countries, since the treatment of ankle

fractures in the elderly population is highly demanding due to increasing medical (mal-union, non-union, soft-tissue problems) and sociological (institutionalizing) problems (Hasselman et al. 2003).

2.3.2 Operative treatment of ankle fractures

The most widely used technique in the treatment of displaced ankle fractures is that recommended by the AO-ASIF group (Rüedi 2000). It is based on the reconstruction of the ankle mortise through exact reduction of the fibula restoring the anatomic fibular length. After that the tibial fragments are reduced, and finally the syndesmotic stability is tested and, if necessary, fixed. The fixation is provided by steel screws, plates, and wires. Fibular fixation constitutes an interfragmentary screw or screws whenever possible, with supplementary plate fixation if needed or when interfragmentary screw fixation is not possible. Tibial fragments are fixed by interfragmentary screws with the exception of small avulsion fragments which may be fixed by wires and cerclage.

When bioabsorbable fracture fixation is used, the same anatomic fundamentals apply to the reduction of fracture fragments (Rokkanen and Törmälä 1996). The fixation is provided by rods or screws. If rods are preferred, the fracture is temporarily fixed by clamps, a channel is drilled, measured, and rinsed for improved implant glide, and the rod is inserted with an applicator, the piston of which may be gently hammered. It may be useful to soak the rod in subcutaneous fat prior to insertion for improved glide. If more than one rod is used for fragment fixation, the first drillbit may be left in its channel to stabilise the temporary fixation, while the other rod is inserted. After inserting the rods the parts possibly protruding are cut to the bone surface level by an oscillating saw or a heat wire cutter. The applicator, when used correctly, will ensure that the end of the rod will be implanted subcortically. For screw fixation a channel is drilled, measured and tapped. Then it should be rinsed to remove any bone debris that might harm the tap of the screw. The screw is inserted with its driver to the desired depth; the glide of the screw should be smooth. If there are any protruding parts after implantation they should be removed by an oscillating saw or heat cutter. If the head of the screw is left in place, it should always be sunk; however, it is not necessary to leave the head of the screw on in purpose to improve the fixation's rigidity.

In the technique described by the AO-ASIF group the syndesmotic disruptions are treated using a transfixation screw: a screw inserted from the lateral cortex of the distal fibula through three or four cortices to hold the fibula in *incisura fibularis* (Rüedi 2000). A four-cortex fixation is more secure, while three-cortex fixation will probably allow some movement of the fibula for more physiological ankle movements (Ebraheim et al. 1997b). Removal of the screw is recommended after syndesmotic healing 8-12 weeks post-operatively. Some institutions prefer to leave the screw in if there are no local symptoms of it; osteolysis around the screw hole will often allow sufficient movements for the ankle joint (Michelson 1995). However, this may later cause pain under loading and, if the screw breaks, removal of it may prove difficult (Amendola 1992).

Also other, more flexible techniques have been described for syndesmotic fixation. Their common goal is to try to avoid the removal operation. Seitz et al. (1991) used a “flexible syndesmosis implant” which was a strong suture loop to hold the fibula in its place during the immobilization period. They report favourable results for 12 patients with a minimum follow-up of two years. A special intramedullary device, the ANK nail, has also been used for syndesmotic fixation. It is an intramedullary nail which secures a simple lateral malleolar fracture and holds the fibula in its place for syndesmotic ligament healing (Kabukcuoglu et al. 2000). The authors present two-year follow-up results from a series of 49 patients with good or excellent results for 41 patients and three post-traumatic arthroses observed.

Bioabsorbable osteosynthesis devices have been used for syndesmotic fixation. In several series conducted at Helsinki University Central Hospital the bioabsorbable implants have been used also in syndesmotic fixation (Hirvensalo 1989, Böstman et al. 1990b, Partio et al. 1992a, Kankare et al. 1995). Although the emphasis of these series is not on the syndesmotic healing making reporting on syndesmotic results cursory, there are no syndesmotic separations reported. Korkala et al. (1999) have reported their preliminary results from a series of seven patients treated with a bioabsorbable syndesmotic screw in conjunction with metallic osteosynthesis. They found acceptable results and are conducting a larger series on the subject. In all of the above-mentioned series PGA implants were used.

Currently three studies have been reported on the use of an SR-PLLA screw in syndesmotic fixation. Thordarson et al. (1997) reported results from biomechanical testing of a 4,5 mm SR-PLLA screw and found the screw sufficient for simulated syndesmotic fixation. Later they reported three-month prelimary results from a randomised series of 32 patients fixed with SR-PLLA or metallic syndesmotic screws with similar results between the comparison groups (Thordarson et al. 2001). In a prospective series of 33 patients, the SR-PLLA syndesmosis screw was found a favourable method for fixation (Hovis et al. 2002). However, in that study there was no comparison group and ten patients were lost before the scheduled follow-up of two years was completed.

3 THE PRESENT STUDY

3.1 The aims of the present study

The aims of the present study were to find answers to the following questions:

1. What is the incidence of infection in elective and traumatologic operations when bioabsorbable self-reinforced PGA or PLLA implants are used?
2. What is the bacterial spectrum associated with infected bioabsorbable self-reinforced PGA and PLLA osteosynthesis implants and does it differ from the bacterial spectrum associated with infected metallic osteosynthesis devices in the operative treatment of displaced ankle fractures?
3. Is there any correlation between the volumes of the bioabsorbable self-reinforced PGA and PLLA osteosynthesis devices used and the incidence of wound infection?
4. Does the implant-bone volume ratio have any correlation with the incidence of wound infection when bioabsorbable self-reinforced PGA implants are used in the treatment of displaced ankle fractures?
5. Can self-reinforced PLLA screws be used in conjuction with metallic fracture fixation devices in the treatment of ruptured tibio-fibular syndesmosis in patients with a displaced ankle fracture?

3.2 Patients

3.2.1 General remarks

The patients of the studies on the incidence of wound infection and the effect of implant volume on wound infections (I-IV) were treated at Helsinki University Central Hospital, and the study on bioabsorbable syndesmosis fixation (V) was conducted at the Kuusankoski District Hospital.

During the whole study period (1984-1994; I-IV), Helsinki University Central Hospital served as a central hospital for an average population of 1,2 million people. At the same time it was also a primary hospital for some parts of the city of Helsinki. The study populations for the papers I-IV are largely overlapping.

The patients of the paper V were operated on at Kuusankoski District Hospital between December 1996 and June 1998. During that period the hospital served as a primary specialized clinic for a population of approximately 75 000 inhabitants.

3.2.2 The incidence of wound infection in association with bioabsorbable implants (Paper I)

The patients were operated on at the Department of Orthopaedics and Traumatology, Helsinki University Central Hospital between November 1984 and December 1992 for various orthopaedic diseases and fresh fractures (Table 3.1). The total number of the patients was 2114, with almost one half of the patients operated on for displaced ankle fractures. Other frequent indications were hallux valgus surgery and fractures around the elbow. The implant material used was PGA in approximately three fourths of the patients.

Table 3.1. The most common indications for use of bioabsorbable fixation devices in orthopaedic surgery 1984-1992 (Paper I)

Orthopaedic diseases		
	Chevron osteotomy for hallux valgus	278
	Bristow operation	60
	Arthodesis of TC-, subtalar, and C-MC joints	24
	Osteochodritis dissecans	17
Rupture of the collateral ligament of the thumb		104
Fresh fractures of		
	Ankle	1043
	Radial head	86
	Olecranon	69
	Condyles of humerus	64
	Carpal or metacarpal bones	48
	Patella	37
	Foot	35
	Knee (intra-articular distal femur or proximal tibia)	30
Others		219
Total		2114

3.2.3 The incidence of wound infection and bacterial spectrum associated with bioabsorbable or metallic fracture fixation in patients with dislocated ankle fractures (Paper II)

There were 3011 displaced ankle fracture patients requiring operative treatment at the Department of Orthopaedics and Traumatology, Helsinki University Central Hospital between 1985 and 1992. Of these patients 26 were operated on with implants made of metallic and bioabsorbable materials and they were thus excluded from the study. The patients under 15 years of age, a total of 26 patients were also excluded. The remaining 3059 patients were included in the analysis (Table 3.2). There were minor differences in the distribution of the fracture type and in the mean ages between the comparison groups (Table 3.3). The patients treated with metallic implants had more often a bi- or trimalleolar fracture and they were on an average seven years older. The implant material used for the treatment was chosen by the surgeon except for some randomized series conducted simultaneously during the present study period (Rokkanen et al. 1985, Böstman et al. 1989a, Hirvensalo 1989, Böstman et al. 1990b, Partio et al. 1992a, Pihlajamäki et al. 1994a, Kankare et al. 1995).

3.2.4 The effect of bioabsorbable implant volume on the incidence of wound infections (Paper III)

All patients admitted to the Department of Orthopaedics and Traumatology, Helsinki University Central Hospital, between November 1984 and January 1994 and treated with bioabsorbable fixation devices were included in the study (Table 3.2). There were a total of 2500 patients with 2044 patients operated on for trauma and 456 patients operated on electively for orthopaedic diseases (Table 3.4).

3.2.5 The effect of the implant-bone volume ratio on the incidence of wound infections (Paper IV)

There were 934 dislocated ankle fracture patients operated on with implants made of self-reinforced polyglycolide (SR-PGA) only at the Department of Orthopaedics and Traumatology, Helsinki University Central Hospital, between August 1985 and January 1994. The implant volumes and locations within each bone were recorded from the patient files. The description of the

implants used and the site of implantation were documented reliably in 846 patients (Table 3.2). These patients comprised the study population. In the study population there were 28 patients with a postoperative wound infection. From the study population trauma, age, and physical condition-matched control patients were selected for the study patients (Table 3.5).

Table 3.2. Study patients included in comparisons

	Paper				
	I	II	III	IV	V
Number of patients	2114	3059	2500	846	30
Sex (Male / Female)	962/1152	1465/1594	1157/1343	-	-
Ankle fracture types					
Unimalleolar / Bi- or trimalleolar		1288/1797	-	-	-
Uni- or bimalleolar / posterior triangle involved		-	-	646/200	18/12

Table 3.3. Operated ankle fracture patients (Paper II)

	Fixation		P-value
	Metallic	Bioabsorbable	
Mean age (range)	46 (8-90)	39 (12-84)	0,01
Fracture type (Unimalleolar/bi- or trimalleolar)	699/1356	591/413	0,01

Table 3.4. Patients treated with bioabsorbable implants in 1984-1994 (Paper III)

	Trauma	Orthopaedic diseases
Number of patients	2044	456
Male/Female	1059/ 985	98/ 358
Mean age (years)	37,5	38,9
Mean operation time (min.)	48,2	49,9

Table 3.5. Paired comparison patients for the effect of the implant-bone volume ratio on wound infections (Paper IV)

	Study patients (wound infection, N=28)	Control patients (without infection, N=28)
Unimalleolar / Bimalleolar fractures	18	17
Posterior triangle involved	10	11
Mean age (years)	44,3	41,9
Mean operation time (min.)	45,5	43,4

3.2.6 Bioabsorbable SR-PLLA or metallic screw for syndesmotic transfixation (Paper V)

All ankle fracture patients with a syndesmotic rupture treated at Kuusankoski District Hospital between December 1996 and June 1998 were called in for a control visit after a minimum follow-up of one year. From a total of 43 patients, 30 agreed to participate (Table 3.2). Of these, 18 were treated with an SR-PLLA syndesmosis screw and 12 with a metallic syndesmosis screw (Table 3.6). Due to the study setting of the historical comparison group, the patients with metallic syndesmosis fixation had longer follow-up times

.

Table 3.6. Ankle fracture patients with syndesmotic rupture (Paper V)

Patients	Syndesmotic fixation	
	SR-PLLA screw	Metallic screw
Number	18	12
Mean age (range)	49,4 (17-78)	46,6 (19-89)
Fracture type		
Lateral malleolus / bimalleolar	12	6
Posterior triangle / trimalleolar	6	6
Mean follow-up (months)	16 (12-23)	27 (16-37)

3.3 Methods

3.3.1 Retrospective studies on the incidence of wound infections and the effect of implant volume on wound infections (Papers I-IV)

All information regarding the treatment of the patients was collected from the patient files. The patients for the studies were identified from the diaries of the operation theatre of Helsinki University Central Hospital (years 1984-1989) and from the computerized data bases (from the year 1989).

The details of the treatment of the patients were re-recorded from the patient files. The recorded details included the diagnosis of the patient and the operative treatment accomplished, the operation time, the implants used, the demographic data, chronic diseases and medications, the date of the infection diagnosis, laboratory and bacteriological findings, and possible other findings related to the tissue reactions occasionally complicating the use of bioabsorbable implants. If there were implant removal operations, the complications of those operations were also recorded.

All infections were diagnosed by a surgeon. An infection was diagnosed if pus was observed, there was secretion from the wound from which the same bacteria were continuously (at least twice) cultured or the patient had a wound infection reaction associated with the systemic manifestations of an infection, i.e. fever, high erythrocyte sedimentation rate, C-reactive protein (CRP) concentration, and leukocyte count. The bacterial cultures were collected either by aspirating pus into a syringe or, if it was not possible, by swabbing the wound. The infection was diagnosed as deep if it affected the implant channel.

3.3.1.1 Calculation of the volumes of implants used (Papers III and IV)

For studies on the volume of the implant (III and IV) the volumes were calculated from the measurements given by the manufacturer of the implants (Bioscience Ltd. and Bionx Implants Ltd.).

3.3.1.2 Estimation of the bone volume in the ankle fracture patients (Paper IV)

For establishing a malleolar bone volume formula there were CT scans and routine radiographs acquired from ankles of 19 volunteers with no previous history of ankle trauma. The CT scanning started at the tip of the lateral malleolus and moved on with five-millimetre increments to a level of ten centimetres above the tibial plafond. From the CT scannings the bone tissue area for each bone on each scanning plane was measured. The coronal and sagittal plane measurements for the fibula and the tibia were taken from the ankle radiographs of the patients. For the fibula, the measurements were taken 10 mm below the level of the tibial plafond, at the level of the plafond, and 20 mm, 50 mm, and 70 mm above the plafond. For the tibia, the measurements were taken similarly from the level of the plafond and above it; no measurements were taken below the plafond. The measurement data was proceeded into a stepwise regression analysis (Sokal and Rohlf 1994) which yielded the final estimation formula for the malleolar bone volume (Fig. 3.1). The formula estimates the bone volume for the fibula distal from the level 50 mm above the tibial plafond. For the tibia the corresponding area is distal from the level 70 mm above the tibial plafond. The bone volume of the malleolar region of the study and control group patients was estimated from the measurements taken from the first postoperative radiographs. The proportion of the implant volume of the bone volume was calculated and the volume percentages compared between the groups. If a syndesmosis screw was used, its volume was estimated to be two thirds in the tibia and one third in the fibula.

3.3.1.3 Implants used in the retrospective series (Papers I-IV)

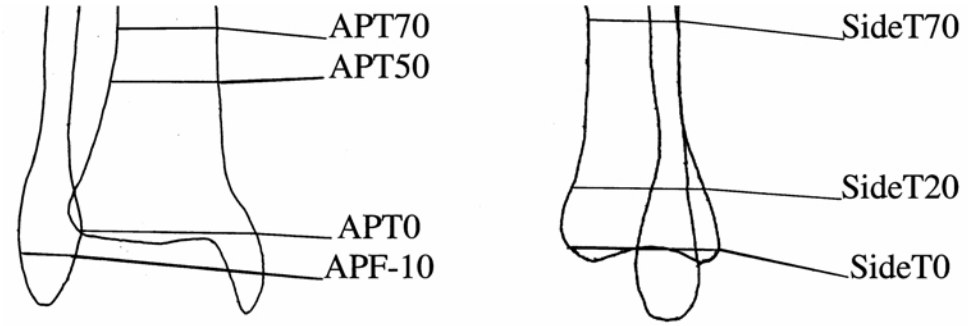
For the first 53 patients, implants made of PGA/PLA co-polymer were used. All the patients were treated for displaced ankle fractures. SR-PGA implants were introduced into clinical work in 1984. Until December 1988 they were made of PGA raw material including a green aromatic quinone dye but afterwards replaced by non-coloured PGA. SR-PLLA implants have been used since 1988. Implants used have included rods, screws, tacks, expansion plugs, and wires. Of these devices, wires have been used in investigative series only for a total of 27 patients (olecranon and pa-

tella fractures). Indications for SR-PGA and SR-PLLA implants include most cancellous bone fractures and osteotomies, and ligament injuries.

Figure 3.1. Malleolar bone volume estimation formula and its measurements (mm^3)

Tibia = -33,2 + 0,659*SideT20 + 0,837*APT50 + 0,761*SideT70 + 0,00588*APT0*SideT0

Fibula = 1,5 + 0,186*APT0 - 0,621*APT70 + 0,024*APT70*SideT70



APT70: coronal measurement, tibia, 70 mm above TC-joint line
APT50: coronal measurement, tibia, 50 mm above TC-joint line
APT0: coronal measurement, tibia, level of TC-joint line
APF-10: coronal measurement, fibula, 10 mm below TC-joint line

SideT70: sagittal measurement, tibia, 70 mm above TC-joint line
SideT20: sagittal measurement, tibia, 20 mm above TC-joint line
Side T0: sagittal measurement, tibia, level of TC-joint line

3.3.2 Bioabsorbable SR-PLLA or metallic screw for syndesmotic transfixation (Paper V)

3.3.2.1 Diagnosis and operative technique

The diagnosis of a syndesmotic rupture was first made in the preoperative radiographs. It was confirmed peroperatively if fibular instability was seen in the *incisura fibularis*.

The SR-PLLA screw used for syndesmotic transfixation measured 4,5 x 60 or 72 millimetres. A four-cortex fixation technique was used. If the screw was too long for the channel, it was cut to the bone surface by a cutting device (HotWire, Bionx Ltd.). For metal screw transfixation, a 3,2 x 32 millimeter corticalis-screw was used (Stratec Medical). It was inserted through three cortices. The syndesmotic screw could be inserted through the lateral malleolus plate if such was used. Post-operatively all patients were immobilized in a plaster cast for six weeks with the first four weeks without weight-bearing. If a posterior triangle fracture was fixed, weight-bearing was not allowed until six weeks postoperatively, with a total of eight weeks of immobilization.

3.3.2.2 Control visit examinations

The control visit included a clinical examination, x-ray, and CT scans. The clinical examination included measurements for ranges of loaded dorsal extensions for both ankles. The subjective results were obtained by a standardized questionnaire (Olerud and Molander 1984).

The plain radiographs were taken with the patients in a standing position. A specially-made rack was used for mortise projections to ensure a similar 15° inward rotation view measured from the axis of the first metatarsal bone. The same rack was used for both feet; it was simply turned upside-down when changed from one foot to another. Three measurements were taken from the plain radiographs: Syndesmosis I: the width of the tibio-fibular clear space at the level of the posterior malleolus on the AP radiograph; Syndesmosis II: the largest tibio-fibular overlap on the AP radiograph; Syndesmosis III: the largest tibio-fibular overlap on the mortise radiograph (Brage et al. 1997).

For CT scanning another rack was prepared that kept the soles of the feet of the patients parallel with the scanning plane and the axis of the first metatarsal

vertical. The measurement was taken one centimetre above the tibial plafond where the longest horizontal distance between the *incisura fibularis* of the tibia and the adjacent fibular cortex could be measured. All the radiological measurements were performed by the same radiologist (R.M.).

Among the patients treated with a bioabsorbable syndesmosis screw there was one patient suffering from morbid obesity (Body Mass Index 63). Due to the weight limitations of the examination table, her CT scans could not be obtained. The average of the measurements of the CT scans for the patients treated with a bioabsorbable syndesmosis screw was thus calculated from the results of 17 patients. The same aforementioned patient was also unable to stand while her feet were attached to the radiographic racks and thus her plain radiographs were taken while she was sitting and stressing her feet.

After obtaining the results from the radiographic studies the measurements from the patient's injured ankle were divided by the measurements from the uninjured ankle. The comparison between the study groups was done between the mean values of the ratios of the measurements.

The measurements for loaded dorsal extensions were taken between the axis of the shaft of the fibula and the floor plane. When measured, the patient stressed the ankle under measurement by more than one half of his/her weight and pushed the knee forward until the heel rose from the floor. The results are presented as deficiencies of extension in the injured ankle. The subjective results were obtained by a constructed questionnaire described by Olerud and Molander (1984) and are presented as point scores.

3.3.3 Statistical methods

For qualitative results, the $\chi 2$ test with Yates's corrections was used. For quantitative results, the Student's T-test was used if parametric comparison was assumed (II) and the Mann-Whitney U-test when non-parametric comparison was assumed. In the Paper IV the paired samples T-test was used for the comparisons between the paired patients.

3.4 Results

3.4.1 The incidence of wound infection in association with bioabsorbable implants (Paper I)

In the study of 2114 patients, the incidence of wound infection in association with different bioabsorbable materials was as follows: PGA/PLA co-polymer 3,8 % (2/53 cases); polyglycolide 4,0 % (58/1441 cases); polylactide 0,7 % (3/420 cases); polyglycolide and polylactide together 6,5 % (12/186 cases); metallic and bioabsorbable material together 14 cases without infections. In association with sinus formation the wound infection rate was 19 % (10 infections /52 sinuses).

3.4.2 The incidence of wound infection and bacterial spectrum associated with bioabsorbable or metallic fracture fixation in the patients with dislocated ankle fractures (Paper II)

There were a total of 121 wound infections in 3111 operated ankle fracture patients. The infection percentages observed with bioabsorbable and metallic fixation were 3,2 % and 4,1 %, respectively. The infections associated with different implant materials are presented in Table 4.1. The incidence of infection within any bioabsorbable subgroup did not differ from that of the metallic fixation group. There were four cases of deep infections (0,4 %) in the bioabsorbable fixation group (three patients treated with SR-PGA implants, one with PGA/PLA implants). The incidence of deep infection with metallic implants was similar (eight cases, 0,4 %). The data of the patients with wound infections is presented in Table 4.2.

The most commonly observed bacteria were Staphylococcus aureus and Staphylococcus epidermidis (Table 4.3). Staphylococcus aureus was cultured from all deep infections in the bioabsorbable group; in the metallic fixation group the staphylococcus species were also the most frequent findings.

Table 4.1. Implant materials and wound infections in the ankle fracture patients in 1984-1992 (Paper II)

Implant material	Cases	Infections	
		Number	Per cent
Metal	2055	85	4,1
Metal and bioabsorbable	26	3	12
Bioabsorbable	1003	33	3,2
PGA/PLA co-polymer	53	2	3,8
SR-PGA	819	29	3,5
Stained only	480	12	2,5
Non-stained only	130	6	4,6
Several	214	11	5,1
SR-PLLA	83	0	0
Several	48	2	4,2
Total	3085	121	3,9

Table 4.2. Ankle fracture patients with wound infections (Paper II)

	Fixation		P-value
	Bioabsorbable	Metallic	
Number of cases	33	85	
Male/Female	21/12	43/42	
Mean age (range)	45 (19-77)	52 (17-82)	0,05
Unimalleolar fractures	18	24	
Bi- or trimalleolar fractures	15	61	0,02[1]
Complicated fractures	2	8	NS
Mean durations			
Trauma to operation (hours)	24 (7-120)	24 (3-120)	NS
Procedure (min)	48 (20-125)	70 (15-170)	NS
Operation to infection (days)	40 (1-164)	33 (1-212)	NS

[1]P-value when comparing fracture type distribution (unimalleolar / bi- or trimalleolar)

Table 4.3. Bacteria cultured from infected wounds (Paper II).

Species	Fixation					
	Bioabsorbable[1]			Metallic[2]		
	N	Per cent	Deep infections	N	Per cent	Deep infections
Staphylococcus aureus	12	36	4	40	47	6
Staphylococcus epidermidis	13	39	2	22	26	1
Diphteroid	4	12		17	20	
Enterobacter cloacae	6	18	1	10	12	4
Beta-hemolytic Streptococcus	3	9		9	11	
Streptococcus agalactiae	3	9		1	1	
Staphylococcus species (indefinite)	4	12		2	2	
Other	19	57		28	33	
Total	64			129		

[1] A total of 33 infection cases of which four deep infections

[2] A total of 85 infection cases of which eight deep infections

3.4.3 The effect of bioabsorbable implant volume on the incidence of wound infections (Paper III)

Of the 2500 patients treated with bioabsorbable implants in 1984-1994, there were 2127 patients whose implant volumes were recorded (Table 4.4). Of these patients, 164 had implants made of more than one material and they were thus excluded from the analysis. In the group of patients treated with implants made of SR-PLLA, there was an over three-fold difference in the mean implant volume between the patients with and without a wound infection. The difference was significant. Of these patients 116 were treated for a rupture of the ulnar collateral ligament of thumb by SR-PLLA tack with an implant volume of 16 mm^3. None of these patients suffered from wound infection. With this subgroup extracted from the rest of the SR-PLLA patients there were 321 patients without wound infection with a mean implant volume of 1330 mm^3. Compared to the mean implant volume of 3152 mm^3 with the infected patients, the difference is still significant, P=0,03. There were no significant mean volume differences observed in the other patient groups.

The total number of ankle fracture patients treated was 1202. Of these patients, the volume data of 146 patients was missing and 73 patients had implants made of more than one material; they were excluded from the analysis. In the ankle fracture patients treated with implants made of SR-PLLA there were no infections in 90 patients with the implant volume recorded. There were 846 ankle fracture patients treated with SR-PGA implants (Table 4.5). Significant differences were found in the mean implant volume of the patients with and without a wound infection when non-stained SR-PGA implants were used or when the SR-PGA group was analysed as a whole. With stained SR-PGA implants there was no such difference. The comparison between the different ankle fracture types is given in Table 4.6. There was a significant difference between the mean implant volume of the patients treated for uni- or bimalleolar fractures.

There was a total of 456 elective operations for orthopeadic diseases in this study. The implant volumes were recorded for 260 and 116 patients treated with implants made of SR-PGA and SR-PLLA only, respectively. The most common operations are presented in Table 4.7. There were nine infections in the patients treated with implants made of SR-PGA and four infections in association with SR-PLLA fixation (Table 4.8). There was a significant difference in the mean implant volume between the patients treated with SR-PLLA implants with and without a wound infection.

Table 4.4. Mean volumes of absorbable implants used for fixation (mm^3).

	Implant material		
	PGA/PLA co-polymer	SR-PGA	SR-PLLA
All patients			
N	49	1466	446
Mean implant volume	1344,1	949,6	996,9
Infected patients			
N	2	52	5
Mean implant volume	2229,5	1217,3	3152,2
Not infected patients			
N	47	1414	441
Mean implant volume	1306,5	939,8	972,5
P-value[1]	NS	NS	0,01

[1] Infected vs. not infected

Table 4.5. SR-PGA implants used in the ankle fracture patients (mm^3).

	Implant material		
	SR-PGA	SR-PGA stained only	SR-PGA non-stained only
All patients			
N	846	449	243
Mean implant volume	1259,2	1210,6	1315
Infected patients			
N	29	11	8
Mean implant volume	1665,2	1206,9	2284,8
Not infected patients			
N	817	438	235
Mean implant volume	1244,7	1210,7	1282
P-value[1]	0,008	NS	0,007

[1]Infected vs. not infected

Table 4.6. Mean implant volumes of different ankle fracture types treated with implants made of SR-PGA only (mm^3)

	Fracture type	
	Uni- or bimalleolar	Posterior triangle involved
All patients		
N	646	200
Mean implant volume	1092,2	1798,6
Infected patients		
N	19	10
Mean implant volume	1415,8	2139
Not infected patients		
N	627	190
Mean implant volume	1082,4	1780,6
P-value[1]	0,02	NS

[1]Infected vs. not infected

Table 4.7. The most common elective orthopaedic procedures (Paper III)

Procedure	Number of procedures	
	SR-PGA	SR-PLLA
Chevron osteotomy	182	44
Op. a.m. Bristow	-	32
Op. a.m. Boytchev	22	-
Osteochondritis dissecans fixations	13	5
Op. a.m. Matti-Russe	10	-
Proximal osteotomy of MT I	9	-
Arthrodeses (mainly wrist)	-	32

Table 4.8. Mean implant volumes of elective operations (mm^3).

	Implant material	
	SR-PGA	SR-PLLA
All patients		
N	260	376
Mean implant volume	154	609
Infected patients		
N	9	4
Mean implant volume	245,2	2648,3
Not infected		
N	251	112
Mean implant volume	150,8	536,2
P-value[1]	NS	0,01

[1]Infected vs. not infected

3.4.4 The effect of implant-bone volume ratio on the incidence of wound infections (Paper IV)

Of the 28 patients with a wound infection, there were 23 patients with an infection in the lateral incision and nine patients with an infection in the medial one. Four patients had infection in both incisions. The mean bone and implant volumes of the patients are presented in Table 4.9 together with a comparison between the mean implant-bone volume ratios of the patient groups. The patients with medial wound infection had significantly higher implant-bone volume ratios than the control patients. Out of five patients in the study group with a medial implant volume exceeding 5 per cent of the tibial bone volume, four had a medial wound infection.

The accuracy of the bone volume estimation formula was tested by comparing the calculations from the plain radiographs of the volunteers with the measurements from the corresponding CT scans. The estimated mean volume for the fibula was 101,1 per cent (range 83-116 %) when compared with the measurements from the CT scannings. The corresponding mean volume for the tibia was 100,1 per cent (range 93-106 %).

Table 4.9. Mean implant and bone volumes and implant-bone volume percentages

	N	Mean bone volume (mm^2)	Mean implant volume (mm^2)	Mean implant-bone volume ratio (range)	P-value
Fibular wound infection	23	9300	741	9,4 (7,7-11,1)	
Control patients	23	9618	847	9,6 (7,8-11,4)	NS
Tibial wound infection	9	44813	1155	4,0 (2,1-5,9)	
Control patients	9	50315	1034	2,8 (1,3-4,3)	0,02

3.4.5 Bioabsorbable SR-PLLA or metallic screw for syndesmotic transfixation (Paper V)

The radiological syndesmosis measurements are presented in Tables 4.10 and 4.11. The differences between the mean ratios of the two study groups were not significant in any of the parameters measured.

The patients treated with a bioabsorbable SR-PLLA syndesmosis screw had a mean deficit of the loaded dorsal ankle extension of 9,9 degrees compared to that of the metallic group of 4,4 degrees. The difference was not significant (P=0,29).

The subjective results from the constructed questionnaire yielded a mean point score of 82 points (range 25-100 points) for the patients treated with a bioabsorbable syndesmosis screw. The corresponding mean score for the metallic syndesmosis screw was 90 points (range 70-100 points). The difference was not significant (P=0,93).

In the study patients no re-operations were performed apart from the osteosynthesis removals. There were no tissue reactions or wound infections in the study patients.

Table 4.10. Results of the radiologic studies
(mean measurement value in millimetres, range in parenthesis)

Measurement	Syndesmosis fixation	
	SR-PLLA	Metallic
CT scanning		
Operated ankle	4.4 (2,8-6,5)	4,0 (1,4-6,3)
Control ankle	4.2 (1,6-7,4)	4,0 (2,6-7,4)
Syndesmosis I		
Operated ankle	5,7 (3,6-8,1)	5,0 (2,8-8,0)
Control ankle	5,1 (3,5-7,8)	4,7 (2,3-6,3)
Syndesmosis II		
Operated ankle	7,8 (3,2-13,4)	8,8 (2,5-13,9)
Control ankle	8,4 (4,8-14,2)	8,5 (3,6-12,6)
Syndesmosis III		
Operated ankle	6,0 (1,5-12,5)	6,8 (1,4- 13,9)
Control ankle	5,5 (3,1-9,3)	6,6 (2,1-10,8)

Syndesmosis I: The width of the tibio-fibular clear space at the level of the posterior malleolus on AP radiograph
Syndesmosis II: The largest tibio-fibular overlap on AP radiograph
Syndesmosis III: The largest tibio-fibular overlap on mortise radiograph

Table 4.11. Mean syndesmosis measurement ratios
(operated ankle / control ankle) and P values

Measurement	Syndesmosis fixation		P-value
	SR-PLLA	Metallic	
CT scanning	1,24	1,09	0,47
Syndesmosis I	1,16	1,19	0,42
Syndesmosis II	0,95	1,04	0,58
Syndesmosis III	1,09	1,03	0,77

4 DISCUSSION

4.1 The validity of the methods and data

The patient demographics in a department of orthopaedics and traumatology have not been previously described on a general level. In the more confined populations of operated ankle fracture patients the present mean age of 39-46 years and fracture type distribution of approximately one third of operated fractures being unimalleolar are quite similar to earlier findings (Lindsjö 1985, Mak et al. 1985, Carragee et al. 1991, Carragee and Csongradi 1993). The present patients operated on by using bioabsorbable implants were slightly younger than those operated on with metallic implants. In earlier series there has been a considerable number of soft tissue complications associated with the operative treatment of ankle fractures in the elderly population (Beauchamp et al. 1983, Mak et al. 1985, Litchfield 1987). This finding was not, however, verified in a more recent study by Makwana (2001). The age distribution of the comparison groups may have biased the present results by raising the infection rates in the metallic fixation group, since patients with a wound infection were found to be older than those without one.

Due to the retrospective nature of the present study, detailed assessment between the incidences and clinical severity of possible confounding factors was not possible (e.g. diabetes mellitus, atherosclerosis obliterans, alcoholism, use of immunosuppressive medication). During the early years of these series, when the use of bioabsorbable implants was still more experimental in nature, there were certain limitations in the use of bioabsorbable implants, but later during the study period no such limitations existed. However, it has to be pointed out that these studies present results from a large series operated on by several surgeons during a time period of ten years, which will make the sampling bias unlikely, though, in a retrospective series, it can never be completely excluded.

The data for the retrospective studies conducted at Helsinki University Central Hospital (I-IV) was collected from the patient files. According to jurisdiction, these files should contain all the relevant data on the treatment of the patient. However, under the present retrospective study setting the completeness of the files cannot be assessed.

When the implants used were recorded correctly, the actual volume data was taken from the records of the manufacturer and assumed to be exact. In some cases, the bioabsorbable implant may have been cut during the operation. In these cases the volume of the portion cut, if mentioned in the patient files, was calculated and subtracted from the implant volume. These subtractions bring in some measurement bias which in this kind of a clinical setting is unavoidable. However, most implants are provided with 5 mm steps in length making the cut portions usually rather small.

In the definition of wound infection a positive culturing result or optionally a wound inflammation reaction associated with systemic laboratory findings was required to differentiate abacterial tissue reactions from infections. There were a few patients who met the clinical and laboratory criteria and were thus diagnosed as infections, even though all bacterial cultures were negative. In a more recent study it has been suggested that, after the initial one-week postoperative rise has settled, CRP levels of more than 36 mg/l are pathognomonic of bacterial complications in ankle fracture patients (Scherer et al. 2001).

The present infections were diagnosed from the patient files according to the presented diagnostic criteria and regardless of what the clinician's diagnosis at the time had been. This makes the diagnostics through the series uniform, but it also brings in some discrepancy between the study results and the clinical work. However, using the clinical diagnosis or nosocomial infection records as the basis for scientific comparisons would bring in an unacceptable measurement bias. In a prospective study it was shown that from 40 to 50 per cent of the true infection cases were not included in the hospital infection registers when the patient files were critically reviewed (Sørensen et al. 2003).

When estimating the implant-bone volume ratios, CT scanning was used as the reference method for bone volume measurements (IV). It has been shown to be the most reliable radiographic method for bone volume measurements (Lönn et al. 1999) with minimal overestimations from the exact bone volume. These overestimations are due to the calculation logarithms dedicating the whole area of one voxel for bone when only a portion of it is occupied by this radiographically dense material (Lönn et al. 1999). For the whole-body tissue

volume determination the estimated volumes measured from the CT scannings have shown a mean difference of 0,85 per cent when compared to the results from tissue density calculations and weightings (Chowdhury et al. 1994).

The bone volume estimation formula seems to yield more accurate results for the tibia than for the fibula. This is probably due to less individual variation in the tibial shape. According to the measurements, there were frequent and considerable individual variations in the fibular bone measurements in the lateral malleolar area. A significant portion of the fibular bone volume is situated under this area, which inevitably leads to less reliable estimates in the mathematical formula. The pairing of the patients in a retrospective study may bias the results, since all details cannot be controlled under the pairing process. As previously mentioned, under a retrospective setting the significance of this bias cannot be assessed. On the other hand, all of the present patients were operated on during their hospital visits indicating detailed assessment of their physical status at that time.

Due to the study setting, the follow-up time of the patients treated with a metallic syndesmosis screw was longer than that of the patients treated with an SR-PLLA screw (V). It may have partially caused the relatively low follow-up percentage of the metallic fixation group. This long follow-up time and low participation percentage may also have caused the observed bias in the fracture distribution between the groups. By the time of the follow-up invitation, the metallic fixation patients with less severe ankle fractures may have healed beyond any complaint thus reducing the motivation to participate in the study. There were six out of 12 patients with posterior triangle fractures in the metallic fixation group as compared to six out of 18 in the SR-PLLA group with such fractures that have in the earlier literature been associated with the poorest clinical outcome (Langenhuijsen et al. 2002).

CT scanning was chosen as reference method for syndesmotic measurements. In a previous experimental study it was proved to be the most sensitive radiologic method to discover a widened syndesmosis (Ebraheim et al. 1997a). From CT scannings a two-millimetre widening in syndesmosis was discov-

ered with 100 per cent sensitivity; a widening of this size is often neglected in routine radiographs (Kaye 1989, Harper 1993).

To describe the range of movement of the talocrural joint, the loaded dorsal extensions of the ankles were chosen for measurement, and comparison was made between the patient's uninjured ankle and the operated one. The measurement of the loaded dorsal extension has been shown to be easily reproducible (Lindsjö et al. 1985). In this study the measurements were taken by two surgeons (I.S. and P.L.) using the similar technique of marking the proximal end of the fibula on the skin and then measuring the angle between the floor level and the line crossing the proximal fibular marking and the most prominent ridge of the lateral malleolus.

4.2 Comparison with earlier findings

In the studies on the incidence of wound infection in association with bioabsorbable osteosynthesis the largest groups of patients were operated on for dislocated ankle fractures or hallux valgus (I). In earlier reports of the operative treatment of hallux valgus the procedures used vary considerably. The emphasis in these studies has been on other aspects than infections, leaving the number of patients rather small for careful assessment of the risk of infection. The incidence of infection has varied from no infections in 23 feet (Mann and Donatto 1997) to 13 infections in 161 feet (Kuo et al. 1998) when metallic K-wire fixation was used. In a recent series there were one infection in 70 feet when no internal fixation was used (Torkki et al. 2001). In the earlier literature the use of bioabsorbable fixation in hallux valgus surgery has yielded lower incidences of infection compared to the present series, but patient groups have been rather small, fewer than 100 patients per group (Hirvensalo et al. 1991, Burns 1995, Small et al. 1995). In addition, none of these articles gives a clear description of what was regarded as infection, making exact comparisons between the results questionnable.

The degrading SR-PGA implants can sometimes elicit an adverse tissue reaction (Böstman et al. 1990a, Böstman 1991, Böstman 1992, Böstman et al. 1992a, Böstman and Pihlajamäki 2000). With the firstly introduced green-stained polyglycolide implants the incidence of tissue reaction was approximately five per cent (Böstman 1992) and, later, when the quinone dye was removed from the PGA material, the incidence has been approximately three per cent (Böstman and Pihlajamäki 2000). The tissue reaction manifests as an inflammatory reaction which may sometimes develop into fluid accumulation and sinus formation. In the present study secondary infections were found in ten out of 52 sinuses (19 %). Due to the rarity of sinus formation, there is no previous data on infections associated with sinus formation. Sinus formation is treated by incisions and, rarely, if needed, by debridements. If sinus formation is encountered, there is always a considerable risk of secondary infection, and therefore the use of prophylatic antibiotics should be considered accordingly.

In the present study there was a total of 121 infections in 3111 patients (3,9 per cent) operated on for ankle fractures. In previous studies the infection rate has varied considerably, from 1,8 per cent (Lindsjö 1985) to 8,6 per cent (Mak et al. 1985); also incidences between three and five per cent have been reported (Tunturi et al. 1983, Phillips et al. 1985, Finsen et al. 1989, Carragee et al. 1991, Carragee and Csongradi 1993). The definitions for infection diagnosis have often been missing. Lindsjö (1985) reports an additional 3,8 per cent of wound margin necrosis without infection, some of which might have met the present diagnostic criteria for infection. The series by Mak (1985) of 116 patients included three complicated and infected fractures (2,6 per cent), which is far beyond the present results with ten complicated and infected fractures out of 3111 patients (0,3 per cent). In the present study 0,4 per cent of the infections were deep in both implant groups of patients. Compared to earlier reports this is relatively low and it may, again, be due to diagnostic criteria and measurement differences.

In the current study the requirements for deep infection diagnosis were pus extracted from the implant area or radiographic reactions (periosteal or osteolysis), which may have resulted in missing some less fulminant deep infections.

The bacterial spectrum associated with ankle fractures consisted mainly of *staphylococcus* species. This finding is in accordance with earlier culturing results of orthopaedic implants. *Staphylococcus aureus* has been the most often found pathogen, and also coagulase negative *staphylococci* (mainly *epidermidis*) have been frequent findings (Gallinaro et al. 1985, Montanaro et al. 1999, Arciola et al. 2001). *In vitro* studies (Gristina et al. 1993) have shown that the use of non-absorbable polymers favours *S. epidermidis* over *S. aureus*, but it could not be confirmed in a clinical setting. In fact, all the deep infections met in the bioabsorbable fixation group had *S. aureus* cultured from the wound.

In the present study there were patients with wound infections having higher mean volumes of implanted material with the use of SR-PGA implants. In the earlier literature, this aspect of infections has not been studied. A further analysis showed that the correlation between the implant volume and the incidence of wound infection was most prominent when non-stained implants were used and this was noted regardless of the type of the ankle fracture treated. The author has earlier interpreted this finding to show that when bioabsorbable materials are used, several infections are preceded by inflammatory tissue reactions. Later it has been shown that the incidence of tissue reactions does not correlate with the volume of PGA implanted (Böstman and Pihlajamäki 2000), to some extent contradicting the conclusion. Obviously further studies on this subject are needed.

A nearly five times greater difference was found in the mean implant volume of the patients operated on with SR-PLLA implants with wound infection compared to those without infection. Although the difference in the mean implant volume was significant, the total number of infections was only four, making this result still preliminary in nature. The incidence of infection in conjunction with SR-PLLA osteosynthesis seems to be lower than that with any other osteosynthesis material in this study, which may partly be due to the

chemical properties of this material: lactic acid is weaker than polyglycolic acid causing milder tissue reactions (Kobayashi et al. 1992), which, together with the slower degrading process, causes smaller burden to the phagocytosing macrophage-population or the "debris clearing capacity" of the tissue (Majola et al. 1991, Pihlajamäki et al. 1994b, Matsusue et al. 1995, Böstman and Pihlajamäki 2000).

Significant positive correlation was found between the incidence of wound infection and the implant-bone volume ratio on the tibial side, when SR-PGA implants were used for ankle fractures (IV). For fractures of the lateral malleolus no such correlation existed. There are no previous studies on this subject. The present bone volume estimation formula yields the bone volume distal from the line 70 mm above the talocrural joint line for the tibia and 50 mm above the talocrural joint line for the fibula. This is the area where the bioabsorbable ankle fracture fixation concentrates on, and, based on the anatomic studies on the circulation within the distal tibia and fibula (Giebel et al. 1997), it was assumed that the concentration of degrading metabolites from implants is not clinically significant outside this area. The result of this study indirectly supports the previous assumption that tissue reaction is a risk factor for wound infection, since the positive correlation in the poorly vascularized tibia was significant, whereas no such finding was seen in the fibula. However, it has to be pointed out that the total number of infections on the medial side was only nine making definitive conclusions too early to be drawn. Obviously larger series are needed on the subject.

In the earlier literature there is one experimental cadaver study on the bioabsorbable SR-PLLA syndesmosis screw (Thordarson et al. 1997). It showed that the mechanical strength of a 4,5 mm SR-PLLA screw was sufficient for simulated syndesmosis fixation. Later the same institution has published preliminary three-month results from their prospective series of 32 patients with syndesmotic disruption treated with a similar technique as in the present study (V), with good clinical and plain radiological results (Thordarson et al. 2001).

Korkala et al. (1999) have published a preliminary study of seven ankle fractures with a rupture of the tibiofibular syndesmosis in which the syndesmotic

rupture was treated with biodegradable SR-PGA screws in conjunction with metallic osteosynthesis. They describe satisfactory results in all but one patient who suffered from transient sinus formation and intraosseal osteolysis.

No tissue reactions were seen in the present bioabsorbable SR-PLLA syndesmosis screw series. With the right operation technique the likelihood of a foreign-body reaction will be diminished (Rokkanen et al. 2000). The screw ends should be both cut to the level of the bone surface. In the literature the only foreign-body reaction asociated with an SR-PLLA screw has occurred in an ankle fracture patient with the screw head left prominent above the bone surface (Böstman and Pihlajamäki 1998, Böstman and Pihlajamäki 2000).

The measuring of the loaded dorsal extensions of the ankles was performed to confirm the present static radiological results by dynamic clinical measurements. The movement of loaded dorsiflexion in the intact ankle involves several components all of which play a significant role in syndesmotic trauma and fixation: a syndesmosis screw extending through four cortices and left in place can, in theory, cause a significant obstacle for dorsiflexion by disabling fibular rotation.There was no significant difference between the deficiencies of extension among the study patients. The small difference observed may be explained by the longer follow-up times of the metallic fixation patients. The patients who have sustaind ankle fractures have been shown to benefit up to nine years of the follow-up (Lehto and Tunturi 1990).

4.3 Future prospects

The results of the present study suggest that in the indications investigated the implant material does not have a clinically relevant effect on the wound infection rate or on the other parameters measured from wound infections. On the other hand, if the surgeon is more familiar with metallic osteosynthesis devices, the possibility to use a bioabsorbable SR-PLLA screw in conjunction with metallic devices for syndesmosis fixation brings apparent simplicity to the treatment, saves the patient one additional out-patient department visit, and also helps in directing the resources of the hospital towards more productive operations (Böstman and Pihlajamäki 1996).

Presently, the selection of commercially available bioabsorbable implants has come down to polylactide-based implants with the termination of production of implants made of PGA. The development in material technical knowledge has resulted in different stereoisometric co-polymers that benefit from differing bending and absorbing properties of D- and L-lactide to adjust the properties of the implant to the specific indication. For these purposes also other material combinations are being developed, including PLA/PGA co-polymers. During the recent years the focus of development in the clinical use of bioabsorbable implants has turned more from devices used for osteosynthesis towards those to be used for soft-tissue injuries along with the introduction of different meniscus, rotator cuff and knee ligament fixation implants.

Although the development of biodegradable osteosynthesis devices has continued for almost four decades now, there are still thrilling prospects for future investigation. Up to the present, these materials have been used as “passive” fixation devices, as their predecessors were. With a dynamic material component, it may be possible, not only to provide healing stability for the fracture, but also to bring in bioactive substances, such as growth factors, to improve the fracture healing (Tielinen et al. 1998, Tielinen et al. 1999, Schmidmaier et al. 2001, Raschke et al. 2002). As for the subject of the present study, the ability of bioabsorbable polymers to act as antibiotic carriers has already been shown (Garvin et al. 1994, Blanco-Prieto et al. 2002, Mollo and Corrigan 2002). Is it mechanically possible to combine this function with fracture fixation, and would it also bring benefits for the treatment of complicated ankle fractures, remains to be seen.

5 CONCLUSIONS

The results of the present study can be concluded as follows:

1. In a large series with orthopaedic and traumatologic indications involved, the incidence of infection in conjunction with bioabsorbable osteosynthesis devices ranges from three to four per cent.
2. In ankle fracture patients, most wound infections are caused by *staphylococcus* species. Deep infections are rare, approximately 0,4 per cent, and are caused by several species with frequent staphylococcal involvement. There is no difference between the bacterial floras associated with bioabsorbable or metallic implants.
3. Increasing the implant volume causes a higher incidence of wound infection when modern, non-stained implants are used. The increase in the incidence of infection is most prominent when SR-PLLA implants are used.
4. Increasing the implant-bone volume ratio causes a higher incidence of wound infection on the tibial side. On the fibular side no such correlation exists.
5. In conjunction with metallic fracture fixation, an SR-PLLA screw is well tolerated for syndesmotic transfixation and it produces similar clinical and radiological results but without need for removal operation.

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