CHAPTER 2

TRENDS IN MINISCREW IMPLANT DESIGN AND USE FOR ORTHODONTIC ANCHORAGE: A SYSTEMATIC LITERATURE REVIEW

2.1 Introduction

To achieve excellent results during orthodontic treatment adequate control of anchorage is necessary. Conventional methods for obtaining anchorage in orthodontics relied mainly on the use of either intra- or extra-oral devices (Proffit *et al.*, 2007). However, anchorage control may be compromised because of the patients' lack of compliance (Samuels, 1996). As a consequence, loss of anchorage may ensue, compromising the treatment outcomes (Cope, 2005).

The use of screws or implants inserted into the bone has become an alternative for providing maximum anchorage in orthodontics without the need for patient compliance (Cope, 2005). The most common skeletal anchorage devices are miniscrew implants because of their reduced size, low cost and versatility of clinical use (Carano *et al.*, 2005b; Chung *et al.*, 2004; Lin and Liou, 2003).

Recently, a wide variety of miniscrew implants with several sizes and designs have been developed. Variations in the geometry of the implants may affect the biomechanical properties of both the implant and the surrounding bone (Himmlova *et al.*, 2004; Holmgren *et al.*, 1998). Therefore, the purpose of this study was to perform a systematic review of the literature to assess the most frequently used sizes and shapes of miniscrew implants, including length and diameter, to evaluate current trends in the use of miniscrew implants in orthodontics.

2.1.1 Classification of miniscrew implants

The major components of the miniscrew implants are head, neck, platform and body (Figure 2.1). Miniscrew implants can be classified according to the particular characteristics of the shape (profile) of the body or the type of thread. The shape of the body can be classified into cylindrical, conical or hybrid types (Figure 2.2) (Carano *et al.*, 2005a). The cylindrical or parallel-sided miniscrew implant presents a constant diameter throughout the length of the implant, resulting in parallel surfaces along the screw (Figure 2.2a). The conical shape, or pure taper, has a gradual reduction of the diameter toward the tip of the miniscrew (Figure 2.2b). The hybrid type presents a dual core that combines both cylindrical and conical structures in the same miniscrew. Therefore, the miniscrew can present a coronal cylindrical portion combined with an apical taper portion (Figure 2.2c) or a coronal taper portion and an apical cylindrical portion (Figure 2.2d).

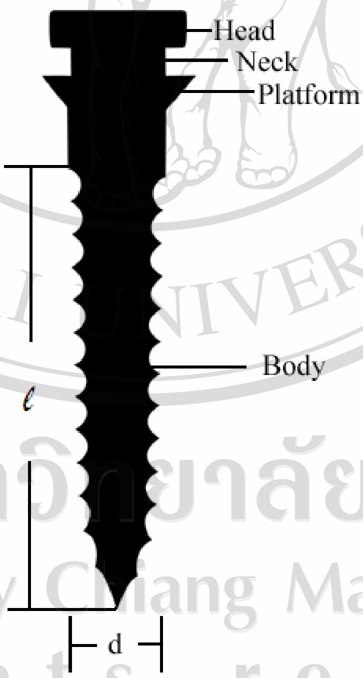

Figure 2.1 Components of miniscrew implant

Note; d = diameter of miniscrew implant, l = length of miniscrew implant

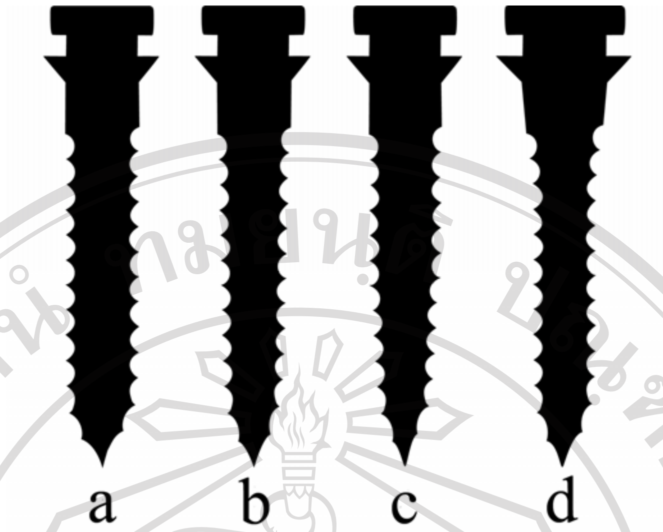

Figure 2.2 Shape of miniscrew implant
Note; a = cylindrical shape, b = conical shape, c = hybrid shape (coronal cylindrical portion combined with an apical tapered portion), d = hybrid shape (coronal tapered portion combined with an apical cylindrical portion)

Miniscrew implants can also be classified, according to the shape of the thread, into non-tapping or self-tapping types. A non-tapping type miniscrew implant has a helical shaft, bluntly threaded throughout its entire length. This implant fits only into a tapped hole. In contrast, self-tapping miniscrew implants have a sharp thread that cuts into the bone without tapping (Sowden and Schmitz, 2002).

Miniscrew implants can also be classified according to the sharpness of their tips, into pre-drilling and self-drilling types (Carano *et al.*, 2005a; Heidemann *et al.*, 2001; Kim *et al.*, 2005; Sowden and Schmitz, 2002). Pre-drilling miniscrew implants have blunt tips and it is necessary to drill a pilot hole before their insertion into the bone (Heidemann *et al.*, 2001; Kim *et al.*, 2005). Self-drilling miniscrew implants have a sharp corkscrew tip with cutting flutes and can be directly inserted into the bone (Kim *et al.*, 2005; Sowden and Schmitz, 2002).

2.1.2 Insertion site

The miniscrew insertion site was divided into two main groups; dentoalveolar and non-dentoalveolar bone sites of maxilla and mandible. The dentoalveolar bone sites included the buccal and palatal/lingual dentoalveolar aspects of maxilla and mandible, while the non-dentoalveolar bone sites included all remaining miniscrew sites, such as the palatal bone, maxillary tuberosity, zygoma and retromolar areas.

2.2 Materials and methods

2.2.1 Search strategy

To identify all articles that examined properties of miniscrew implants, a literature survey was conducted in the Medline (http) and Elsevier (http://www. scopus.com/scopus/ home.url) data bases. The survey covered the period from the inception of the Medline and Elsevier data bases to December 2006 and the keywords for this literature review were; "miniscrew," "micro-screw," "micro-implant," "mini-implant" and "skeletal anchorage for orthodontics."

2.2.2 Selection criteria

Inclusion criteria for this literature survey were English language human studies and case reports. Exclusion criteria were animal studies, *in vitro* studies, review articles, letters, interviews and articles not written in English. The numbers of articles identified by the search strategy are listed in Table 2.1.

2.2.3 Data collection

The following data were collected: author; year of publication; study design; implant manufacturer (where identified); shape of body; type of thread; insertion site; diameter and length of miniscrew implant. In this study, the diameter of the miniscrew implant refers to the widest part of the body of the miniscrew implant; the length of the miniscrew refers to the distance between the beginning point of the thread and the tip of the miniscrew implant (Figure 2.1). Subsequently, data were analyzed and described in percentages.

Table 2.1 Numbers of excluded and included articles in this systematic review

Criteria	Number
Inclusion criteria	
Human studies	28
Case reports	59
Total	87
Exclusion criteria	
Animal studies	11
Laboratory studies	3
Other (review articles, letters, interviews, articles written in a language other than English)	20
Total	34
Total number of surveyed articles	121

2.3 Results

From 121 articles found only 87 articles met the criteria of selection. The included studies were 28 human studies and 59 case reports.

From the total of 87 selected articles, 64 articles showed the diameter and length of the miniscrew implants. Among 1240 miniscrew implants described in these selected studies, 1123 implants were inserted into the dentoalveolar bone (90.6%) and 117 implants were inserted into the non-dentoalveolar bone (9.4 %) (Figure 2.3).

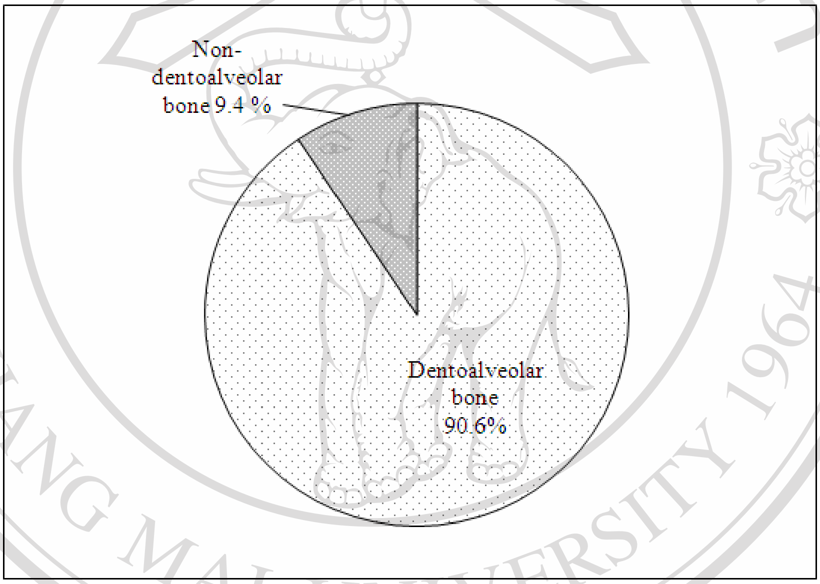

Figure 2.3 Percentages of miniscrew implants distributed by insertion site

2.3.1 Diameter of miniscrew implant

The diameters of miniscrew implants varied from 1.0 to 2.3 mm. In general, the most frequently reported diameters were 2.0 mm (35.8%), 1.2 mm (28.3%) and 1.6 mm (12.7%). In the dentoalveolar bone, the most frequently used diameters were 2.0 mm (36.8%), 1.2 mm (28.0%) and 1.6 mm (13.5%). For the non-dentoalveolar bone, such as, zygoma, palatal bone, or retromolar, the most frequently used diameters used were 1.2 mm (31.6%), 2.0 mm (26.5%) and 1.8 mm (21.4%). The most frequently used diameters of miniscrew implants in the dentoalveolar bone of maxilla were 2.0 mm (42.3%), 1.2 mm (25.9%) and 1.6 mm (12.7%). For the dentoalveolar bone of mandible, the most frequently used diameters were 1.2 mm (33.0%), 2.0 mm (23.1%), and 1.5 mm (16.5%) (Table 2.2).

2.3.2 Length of miniscrew implant

Miniscrew implants were available in lengths of 4.0 to 17.0 mm. In general, the most frequently used miniscrew lengths were 8.0 mm (38.1%), 6.0 mm (24.0%) and 9.0 mm (9.0%). The most frequently used lengths of miniscrew implants in the dentoalveolar bone of the maxilla were 8.0 mm (42.8%), 6.0 mm (21.2%) and 9.0 mm (8.9%). For the dentoalveolar bone of mandible, the most frequently used lengths were also 8.0 mm (34.9%), 6.0 mm (32.4%) and 9.0 mm (11.2%) (Table 2.3).

The most frequently used lengths in the dentoalveolar bone were 8.0 mm (40.5%), 6.0 mm (24.4%) and 9.0 mm (9.5%), respectively. For the non-dentoalveolar bone, the most frequently used lengths were 14.0 mm (23.1%), 6.0 mm (19.7%) and 8.0 mm (14.5%) (Table 2.3).

Table 2.2 Numbers and percentages of diameters of miniscrew implants distributed by area

Insertion site	Diameter (mm)								Total	%
	1.0	1.2	1.3	1.5	1.6	1.8	2.0	2.3		
Dentoalveolar bone										
Maxilla										
Anterior	0	15	0	0	1	0	11	0	27	2.2
Posterior	5	193	22	62	101	59	328	5	775	62.5
Maxillary total	5	208	22	62	102	59	339	5	802	64.7
%	0.6	25.9	2.7	7.7	12.7	7.4	42.3	0.6	100.0	
Mandible										
Anterior	0	8	0	0	0	0	7	0	15	1.2
Posterior	5	98	22	53	50	2	67	9	306	24.7
Mandibular total	5	106	22	53	50	2	74	9	321	25.9
%	1.6	33.0	6.9	16.5	15.6	0.6	23.1	2.8	100.0	
Dentoalveolar total	10	314	44	115	152	61	413	14	1123	90.6
%	0.9	28.0	3.9	10.2	13.5	5.4	36.8	1.2	100.0	
Non-dentoalveolar bone										
Zygoma	0	0	0	0	0	0	15	15	30	2.4
Maxillary tuberosity	0	1	0	1	0	0	1	0	3	0.2
Palate	0	1	0	0	4	25	8	0	38	3.1
Retromolar	0	35	0	0	1	0	7	3	46	3.7
Non-alveolar total	0	37	0	1	5	25	31	18	117	9.4
%	0.0	31.6	0.0	0.9	4.3	21.4	26.5	15.4	100.0	
Grand Total										
Number	10	351	44	116	157	86	444	32	1240	100.0
%	0.8	28.3	3.5	9.4	12.7	6.9	35.8	2.6	100.0	

Table 2.3 Numbers and percentages of length of miniscrew implants distributed by area

Insertion site	Length (mm)													Total	%
	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	17.0		
Dentoalveolar bone															
Maxilla															
Anterior	0	1	7	0	8	1	1	0	5	0	4	0	0	27	2.2
Posterior	0	1	163	16	335	70	35	43	9	33	5	58	7	775	62.5
Maxillary total	0	2	170	16	343	71	36	43	14	33	9	58	7	802	64.7
%	0.0	0.2	21.2	2.0	42.8	8.9	4.5	5.4	1.7	4.1	1.1	7.2	0.9	100.0	
Mandible															
Anterior	0	0	5	0	6	1	2	0	1	0	0	0	0	15	1.2
Posterior	8	8	99	14	106	35	4	17	0	9	2	4	0	306	24.7
Mandibular total	8	8	104	11	112	36	6	17	1	9	2	4	0	321	25.9
%	2.5	2.5	32.4	4.4	34.9	11.2	1.9	5.3	0.3	2.8	0.6	1.2	0.0	100.0	
Dentoalveolar total	8	10	274	30	455	107	42	60	15	42	11	62	7	1123	90.6
%	0.7	0.9	24.4	2.7	40.5	9.5	3.7	5.3	1.3	3.7	1.0	5.5	0.6	100.0	
Non-dentoalveolar bone															
Zygoma	0	0	13	0	0	1	0	0	0	0	2	0	14	30	2.4
Maxillary tuberosity	0	0	1	0	0	2	0	0	0	0	0	0	0	3	0.2
Palate	0	0	0	3	4	2	0	0	0	4	25	0	0	38	3.1
Retromolar	10	9	9	3	13	0	2	0	0	0	0	0	0	46	3.7
Non-alveolar total	10	9	23	6	17	5	2	0	0	4	27	0	14	117	9.4
%	8.5	7.7	19.7	5.1	14.5	4.3	1.7	0	0	3.4	23.1	0	12.0	100.0	
Grand total															
Number	18	19	297	36	472	112	44	60	15	46	38	62	21	1240	100.0
%	1.5	1.5	24.0	2.9	38.1	9.0	3.5	4.8	1.2	3.7	3.1	5.0	1.7	100.0	

2.3.3 Miniscrew components

From the total of 1240 miniscrew implants identified in the reviewed articles, 1169 showed the trademark, and, as a result, the components of miniscrew could be identified. All selected articles showed self-tapping miniscrews. In the reviewed articles, 760 miniscrews (65.0%) were cylindrical shape, 297 (25.4%) were conical, while 112 (9.6 %) were hybrid. The self-drilling type accounted for 462 miniscrews (39.5%), while 707 (63.5%) were of the pre-drilling type. (Table 2.4).

Table 2.4 Numbers and percentages of miniscrew implant features reported in reviewed articles

Topic	Numbers of miniscrew implant	%
Identified miniscrew implant	1169	94.2
Unidentified miniscrew implant	71	5.8
Total number	1240	100.0
Type of thread		
Pre-drilling	707	63.5
Self-drilling	462	39.5
Total	1169	100.0
Shape of body		
Cylindrical shape	760	65.0
Conical shape	297	25.4
Hybrid shape	112	9.6
Total	1169	100.0

2.4 Discussion

Several types of titanium miniscrew implants have been developed to provide maximum skeletal anchorage for orthodontic application, with a wide variety of sizes and designs. These changes in the geometry of the implants greatly affect the biomechanical properties of both the implant and the surrounding bone (Himmlova *et al.*, 2004; Holmgren *et al.*, 1998).

In the present study, a systematic review of the literature was performed to assess the most frequently used sizes and designs of miniscrew implants currently used in orthodontics. To the authors' knowledge, there has been no previous systematic review or meta-analysis published regarding the optimal size of miniscrew implants.

According to the results, the number of miniscrews inserted into the dentoalveolar sites was relatively higher than those inserted into non-dentoalveolar sites (Figure 3). The main explanation for the preference for the dentoalveolar sites is the possibility of applying relatively simple force system and simple surgical procedures (Chae, 2006; Park *et al.*, 2004; Suzuki and Suzuki, 2007a).

The diameter of the miniscrew implant has been reported to be one of the most important factors related to failure rate (Chen *et al.*, 2006a; Cheng *et al.*, 2004; Fritz *et al.*, 2004; Miyawaki *et al.*, 2003; Park *et al.*, 2006). The use of miniscrew implants of less than 1 mm in diameter has been shown to result in significantly high failure rates (Miyawaki *et al.*, 2003). Miniscrew implants with large diameters result in increased implant-bone interface, resulting in improved primary stability. Moreover, increased size of miniscrew implants prevents risks of miniscrew fracture during insertion or removal procedures (Buchter *et al.*, 2005; Chen *et al.*, 2006b; Tseng *et al.*, 2006).

However, larger implant diameters may pose problems with penetration of adjacent anatomical structures (Costa *et al.*, 2005; Deguchi *et al.*, 2006; Ishii *et al.*, 2004; Poggio *et al.*, 2006). Since the preferred site for the miniscrew implant placement is in the dentoalveolar bone, the amount of interradicular bone plays an important role in the selection of the appropriate diameter used.

The anatomical limitations of the dentoalveolar bone have guided the optimization of the sizing of miniscrew implants (Gautam and Valiathan, 2006; Huang *et al.*, 2005). According to Deguchi *et al*. (2006) a minimum clearance of approximately 1.0 mm should be maintained, mesially and distally, between the miniscrew implant and the lamina dura of adjacent dental roots to allow sufficient space for periodontal health. Therefore, a miniscrew implant 1.5 mm in diameter could be considered safe if at least 3.5 mm of space are available between the lamina dura of adjacent teeth (Poggio *et al.*, 2006).

Because of limited space in the dentoalveolar bone, several clinical approaches, such as the use of surgical guides (Morea *et al.*, 2005; Suzuki and Buranastidporn, 2005; Suzuki and Suzuki, 2007b), templates (Wu *et al.*, 2006), and stents (Kitai *et al.*, 2002) were developed to prevent damage to anatomical structures during miniscrew implant insertion. The insertion of miniscrew at angulations has also been suggested as an effective clinical approach to reduce the risks of root damage (Aranyawonsakorn *et al.*, 2007; Deguchi *et al.*, 2006; Poggio *et al.*, 2006).

In the present study, the diameter of miniscrew implants varied from 1.0 to 2.3 mm. Although dentoalveolar and non-dentoalveolar sites have particular anatomical characteristics, no noticeable difference in the diameter of miniscrew implants was observed.

In the dentoalveolar site, noticeable difference was observed in the diameter of miniscrew implants used for the maxilla and mandible. According to the results, the most frequently used diameter for maxilla was larger than those used in mandible.

One possible explanation for the difference in diameter of miniscrews between maxilla and mandible is the availability of interradicular space (Deguchi *et al.*, 2006; Schnelle *et al.*, 2004). Because the availability of interradicular space in the maxillary bone is generally greater than in the mandible, the insertion of miniscrews of large diameter in maxillary sites becomes possible.

The quality of the recipient bone also plays an important role in the biomechanical properties of miniscrews (Reitman *et al.*, 2004). Since the mandible presents with relatively more compact and dense cortical bone than does the maxilla, consequently increasing significantly the insertion torque, larger diameter miniscrews would be required to avoid risks of fracture during their insertion (Kravitz and Kusnoto, 2007).

A wide variation was observed between the diameters of miniscrews used in the various non-dentoalveolar areas. For example, in the retromolar sites, although a large amount of bone for the insertion of miniscrews is available, the most frequently used miniscrews were those with reduced diameters. In contrast, for the palatal sites, miniscrews with relatively large diameters were used. The results suggested that miniscrews that were specifically designed to be inserted into the dentoalveolar sites were also applied in the non-dentoalveolar sites. Moreover, for insertion only in the zygomatic area specific miniscrews with large size had been especially developed.

The length of miniscrew implants is an important factor related to failure rate. Long miniscrew implants produce an increased contact area between the miniscrew implant and bone. Consequently their use might increase the primary stability and success rate (Buchter *et al.*, 2005; Chen *et al.*, 2006a; Chen *et al.*, 2006b; Tseng *et al.*, 2006).

In the present review, a wide variety of miniscrew lengths were used to obtain skeletal anchorage in several areas of the jaws. In general, the most frequently used lengths of miniscrew implant were 8.0 and 6.0 mm. No noticeable difference was observed between the lengths of miniscrew implants used in maxillary and mandibular dentoalveolar bone.

These results are in agreement with those of Poggio *et al*. (2006) who recommended miniscrew lengths of 6.0 to 8.0 mm in the posterior region of the dentoalveolar bone of the maxilla and mandible. However, since the mandible presents with relatively more compact and dense cortical bone than does the maxilla (Costa *et al.*, 2005; Deguchi *et al.*, 2006), the use of different miniscrew lengths would provide different results in terms of miniscrew stability. Moreover, long miniscrews inserted in the mandibular bone would significantly increase the risks of miniscrew fracture during their insertion (Kravitz and Kusnoto, 2007).

In the non-dentoalveolar sites, a wide variation between the lengths of miniscrews was observed. Relatively long miniscrews were used in the palatal and zygomatic sites, compared to those used in the retromolar sites.

Gelgor *et al.* (2004) inserted relatively long miniscrews obliquely across the palatal suture in order to increase primary stability. However, the clinical study performed by Miyamoto *et al.* (2005) had shown that implant length had weak correlation with primary stability. Moreover, Kang *et al.* (2007) measured palatal bone thickness and they found that bone thickness in the paramedian area of the palate varied from 4.0 to 11.0 mm. Using implants of greater length than the bone thickness may result in penetration into underlying structures. Therefore, shorter miniscrew implants may be safe for this insertion site.

According to several studies, the mandible, including the retromolar area, has more compact bone when compared with the maxilla (Costa *et al.*, 2005; Deguchi *et al.*, 2006; Gelgor *et al.*, 2004; Poggio *et al.*, 2006). Therefore, a reduction in risk of miniscrew fracture from excessive insertion torque could be achieved by decreasing the length of the miniscrew when compared with those used in other areas of non-alveolar bone.

The results obtained in this study also suggest that the clinical selection of the diameter and length of miniscrews was mainly based on the anatomical characteristics of the recipient bone, i.e. the availability of interradicular space, cortical bone and soft tissue depth, rather than the quality of the recipient bone. Therefore, further studies assessing the biomechanical performance of miniscrews in these areas are required.

Currently, miniscrew implants have been divided in three main groups: cylindrical, conical and hybrid shapes. Although these differences in the geometry of the miniscrew implant could play an important role on the biomechanical properties of the miniscrew implant and bone, only a few studies have been performed to compare the performance of cylindrical, conical or hybrid miniscrews. Kwok *et al.* (1996) and Sakoh *et al.* (2006) compared the performance of surgical screws of different shapes using a mechanical test. It was concluded that the conical screws resulted in more insertion torque than did the cylindrical screws. Therefore, conical screws would result in increased primary stability and, consequently, improved clinical performance compared to cylindrical screws. However, in the present review, the frequency of cylindrical miniscrew use was higher than that of conical miniscrews. Moreover, only a few clinical or experimental studies regarding the shape of miniscrew implants have been reported (Lim *et al.*, 2008; Songa *et al.*, 2007).

Recently, a new type of miniscrew with both cylindrical and conical parts (hybrid shape) has been developed. Although the total number of hybrid miniscrew shapes identified in the reviewed articles was relatively small compared to both cylindrical and conical shapes (Figure 2.4), there was a clear tendency toward the increased use of this new type of miniscrew (Figure 2.5). The main advantage of the hybrid type is the possibility of combining the advantages of both cylindrical and conical miniscrews.

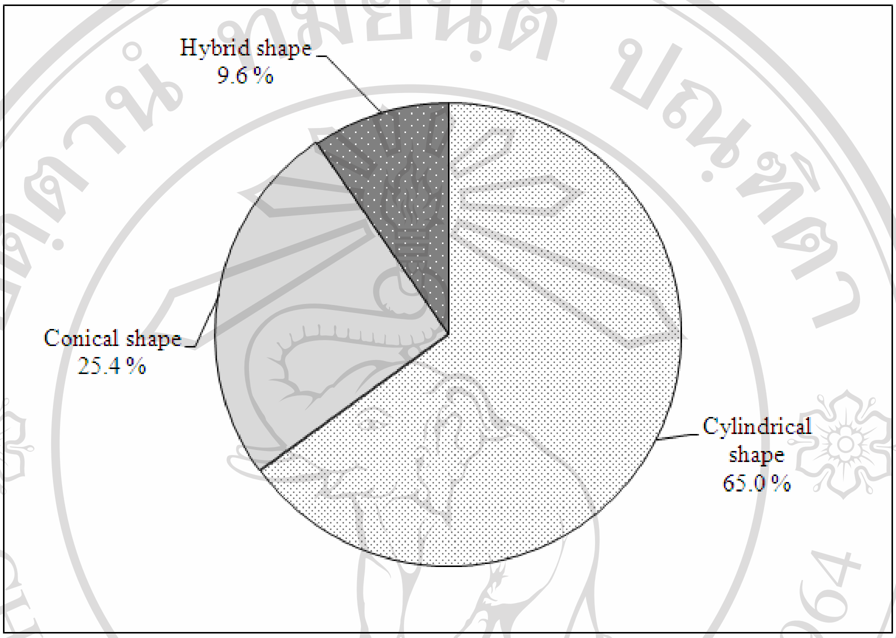

Figure 2.4 Percentages of miniscrew implants distributed by shape

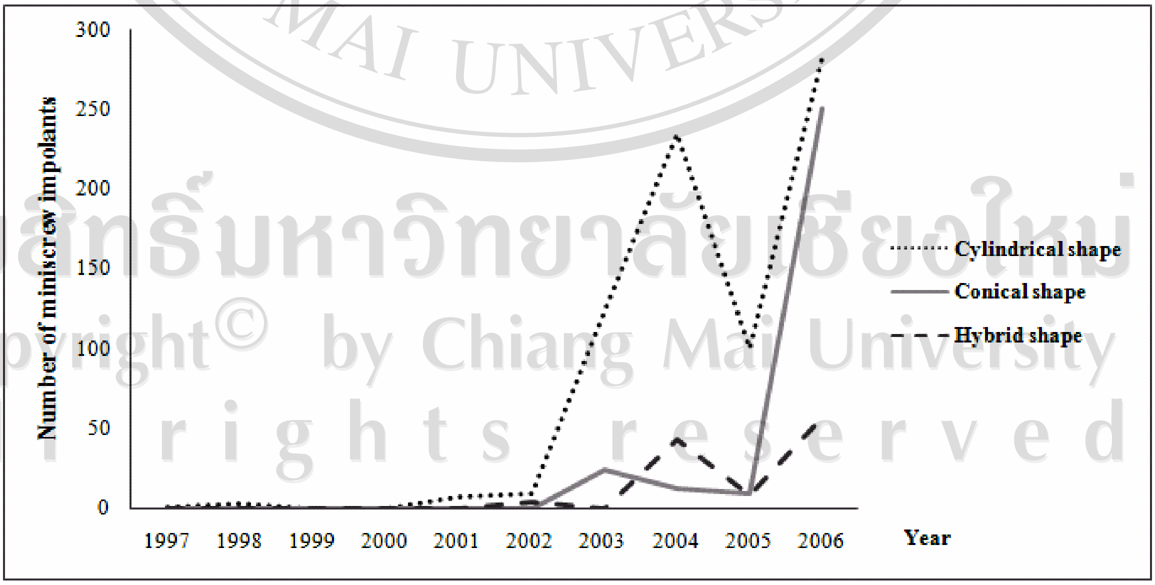

Figure 2.5 Numbers of miniscrew implants by shape, distributed by year

Lim *et al.* (2008) analyzed the insertion torque of cylindrical and hybrid miniscrews. They concluded that hybrid miniscrews provide increased insertion torque compared to the cylindrical types at the tapered part of the screw thread, thus providing increased primary stability.

In general, miniscrew implants have been classified into two major groups according to the shape of their tips, pre-drilling and self-drilling miniscrew types. Both of them present advantages and disadvantages that should be analyzed.

The advantage of self-drilling miniscrew implants is the possibility of simplifying the surgical procedures. Because the self-drilling miniscrew implants have sharp corkscrew tips with cutting flutes they can be directly inserted into the bone without pre-drilling (Kim *et al.*, 2005; Sowden and Schmitz, 2002). However, self-drilling miniscrew implants may increase the risks of root damage if they are misdirected. Moreover, direct insertion into the cortical bone increases the insertion torque significantly, consequently increasing the risk of miniscrew fracture. Manufacturers of self-drilling miniscrews recommend the pre-drilling of a pilot hole before inserting such miniscrews in dense cortical bone, such as in the non-dentoalveolar bone of the mandible.

Although pre-drilling miniscrews require the preparation of the pilot hole before their insertion into the bone, the risks of root damage are reduced. Since these miniscrews present with a rounded tip, they are incapable of penetrating the root surface even if they are misdirected.

Studies assessing the differences between pre-drilling and self-drilling surgical screws have been performed. Sowden and Schmitz (2002) compare the bone-to-screw interface of both self-drilling and pre-drilling screws, using scanning electron microscope. Pre-drilling screws presented a better adaptation to the bone surface compared to the self-drilling screws, suggesting that the damage to the bone can be reduced by the pre-drilling of a pilot hole.

Although, in this review, the frequency of application of the pre-drilling miniscrew was higher than that of the self-drilling type, there is an increasing tendency in practice toward the use of self-drilling miniscrews. The main reason is the reduction of surgical steps for their insertion, thus simplifying the surgical procedures (Kim *et al.*, 2005). However, since the self-drilling miniscrews were developed to be inserted directly into the bone, they require a larger diameter to avoid miniscrew fracture during the placement procedures.

Further studies comparing the mechanical properties of several shapes and designs of currently available miniscrews are necessary to confirm their clinical performance and success rates.

2.5 Conclusions

In the present review, the most frequently used sizes and designs of miniscrew implants were analyzed. Although selection of miniscrew implants depended on anatomical limitations and clinical applications, no standardization for screw selection in terms of diameter, length or shape was observed. Further studies are necessary to evaluate how the differences in size and shape are related to the biomechanical properties of the miniscrew implants.