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ANY CHECK

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임플란트 healing abutment 높이와 타진각도에 따른 타진방식 임플란트 안정성 측정기기의 수치 차이

박양훈[1] · 이성복[1]* · 이석원[1] · 백장현[2] · 이정열[3]

[1]강동경희대학교 치과병원 생체재료 보철과, [2]경희대학교 치과대학 치과보철학교실, [3]고려대학교 구로병원 임상치의학 연구소

Differences in percussion-type measurements of implant stability according to height of healing abutments and measurement angle

Yang-Hoon Park[1], Richard Leesungbok[1]*, Suk-Won Lee[1], Janghyun Paek[2], Jeong-Yol Lee[3]

[1]*Department of Biomaterials and Prosthodontics, Kyung Hee University Dental School Hospital at Gangdong, Seoul, Republic of Korea*

[2]*Department of Prosthodontics, School of Dentistry, Kyung Hee University, Seoul, Republic of Korea*

[3]*Department of Prosthodontics, Institute for Clinical Dental Research, Korea University Medical Center, Korea University, Seoul, Republic of Korea*

Purpose: The purpose of this study was to evaluate the effect of healing abutment height and measurement angle on implant stability when using Periotest and AnyCheck. **Materials and methods:** 60 implants were placed into artificial bone blocks. After implant insertion, 2, 3, 4 and 5 mm healing abutments were installed on 15 specimens, respectively. Insertion torque value, implant stability test, Periotest value were measured. Insertion torque value was controlled between 45 - 55 Ncm. AnyCheck was used for measuring implant stability test and Periotest M was used for measuring Periotest value. Implant stability test and Periotest value were measured at the angles of 0 and 30 degrees to the horizontal plane. Measured values were analyzed statistically. **Results:** Insertion torque value had no significant difference among groups. When healing abutment height was higher, implant stability test and Periotest value showed lower stability. Also when measurement angle was decreased, implant stability test and Periotest value showed lower stability. **Conclusion:** When measuring stability of implants with percussion type devices, measured values should be evaluated considering height of healing abutments and measurement angle. *(J Korean Acad Prosthodont 2018;56:278-86)*

Keywords: Implant stability; AnyCheck; Periotest; Implant stability test; Periotest value; Insertion torque value

서론

오늘날 치과용 임플란트는 부분 무치악 환자, 완전 무치악 환자의 치료에 널리 사용되고 있다. 시술한 치과 임플란트의 미래 성공여부를 내다보는 척도로서 골내에 식립된 임플란트의 안정성(stability)을 수치화하여 비교하는 '안정성 검사(stability test)'가 대표적이다. 치과 임플란트의 안정성은 식립 당시에 측정하여 기록하는 초기 안정성(primary stability)과, 골유착 치유가 진행되면서 얻게 되는 이차 안정성(secondary stability)으로 구분하고 있다.[1] 이들 중 임플란트의 초기 안정성은 임플란트 식립 직후에 얻어지는 기계적인 안정성으로서, 이후에 진행되는 골유착 과정에 영향을 미치기 때문에 임플란트의 성공에 매우 중요한 요소이며,[2] 신생골 형성(new bone formation)과 골 개조(bone remodeling)로 얻어지는 이차적인 생물학적 안정성과는 구별하여 이해해야 한다.[3] 초기 안정성은 식립된 임플란트의 즉시부하와 초기기능력을 부여하기 위해서 반드시 필요한 요소이며, 골

*Corresponding Author: Richard Leesungbok
Department of Biomaterials and Prosthodontics, Kyung Hee University Dental School Hospital at Gangdong, 892 Dongnam-ro, Gangdong-gu, Seoul 05278, Republic of Korea
+82 (0)2 440 7520: e-mail, sbykmw@yahoo.co.kr

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질, 골량, 수술법, 임플란트의 형태 및 표면처리 등의 특성에 의해서 영향을 받는다.[4,5]

초기 안정성과 임플란트 초기 고정력을 측정하기 위해 조직학적 관찰[6], 제거 토크(removal torque) 분석,[7,8] 방사선사진 분석 등의 방법이 소개되었다.[9] 그러나 기계적 측정법들은 골유착이 완성되기도 전에 과도하게 침습적이며, 화상에 의한 판정법들은 객관화된 정량적 정확도가 모호하다는 단점을 가지고 있다.[10] 아직까지 임플란트의 초기 안정성을 임상적으로 측정할 수 있는 기기들이 다양하지 않은 실정에서 자기공진주파수 분석법(resonance frequency analysis, RFA) 방식과 타진방식의 2 가지 측정 방식이 널리 사용되고 있다.[11,12] RFA 방식은 SmartPeg라고 불리는 변환기(transducer)를 측정할 때마다 임플란트에 연결해야 하는데 임플란트의 종류에 따라 맞는 것을 특별히 선택해서 측정해야 하는 번거로움이 있다.[13] 이러한 RFA 방식과는 달리, 타진 방식은 healing abutment (HA) 또는 임플란트 상부보철을 제거하지 않은 상태에서 치유기간 동안에도 필요할 때마다 자유롭게 안정성을 측정할 수 있다는 장점이 있다. 타진방식의 측정기기로는 이미 잘 알려져 있는 Periotest (Medizintechnik Gulden, Modautal, Germany)와 최근에 개발되어 출시된 AnyCheck (Neobiotech Co. Ltd., Seoul, Korea) 등이 있다.

Periotest는 문헌상에 가장 자주 언급되어 있는 측정기기 중 하나다.[14] 금속 막대(metal rod)가 HA 또는 임플란트 상부보철의 표면에 닿은 후 정지하였다가 다시 돌아오는 시간을 측정하여 Periotest value (PTV)로 나타낸다. 4초 동안 총 16회 타진하며, PTV가 0일 때 접촉 시간은 0.426 milliseconds이다. 접촉시간이 0.02 milliseconds 증가하면 PTV는 1이 증가하게 되는데, 계기판에는 -8에서 +50까지의 값으로 표시된다.[15] 임플란트 안정성 수치는 높을수록 임플란트의 동요도가 작다는 뜻이기 때문에, PTV는 측정값이 낮을수록 높은 임플란트 안정성 수치를 의미한다. PTV에 관련된 연구를 살펴보면 Aparicio[16]는 8년 종단적 연구에서 PTV가 골 리모델링과 골유착의 정도와 강한 상관관계를 보이며, 보철물을 제작하기 전에 Periotest를 이용하여 임플란트의 성패 판별이 가능하다고 보고하였다. 그러나, Faulkner 등[14]은 Periotest가 충격을 가하는 위치에 따라서 PTV의 차이가 있음을 발견하였는데, 1 mm 정도의 위치 차이에서 PTV가 1 - 2 정도 변할 수 있으며 같은 위치에서 측정한 경우에서도 측정각도에 따라 PTV 2.5 - 4.0 의 차이가 발생할 수 있다고 보고하였다. 다른 연구에서도 타진 위치 등의 다양한 요인이 PTV 값에 영향을 준다고 하였다.[17,18]

AnyCheck은 타진방식 임플란트 안정성 측정기기로서 2017년에 출시되었다. 임플란트 보철 또는 HA를 3초 동안 6회 타진하여, HA와 접촉하는 시간을 계측하여 implant stability test (IST)로 표시하는 기기이다. IST는 1 - 99의 범위로 표시되며 숫자가 높을수록 접촉시간이 짧고 임플란트 안정성 수치가 높다는 것을 의미한다. IST는 1 - 59에서 낮은 안정성, 60 - 64에서 보통 안정성, 그리고 65이상에서 높은 안정성을 의미한다. 타진 시 59 이하의 낮은 안정성을 나타내는 경우 즉시 타진을 중단하는 안전제어 기능도 갖추고 있다. 측정 시 위치는 먼저 환자를 직립위로 앉도록 하여 임플란트 장축이 지면과 수직이 되도록 위치시킨다. 임플란트 장축에 수직으로, 즉 지면과 평행하도록 기기를 위치시키고 IST를 측정한다. AnyCheck은 지면과 기기가 이루는 각도가 30°이상일 경우 오류로 인식하면서 타진 측정이 중단되는 제어기능이 있기 때문에, 측정 허용 각도를 벗어난 위치에서 각도 차이에 의한 측정오차를 줄일 수 있다. 그러나 아직 장기간의 임상적 사용 데이터가 축적되지 않아 더욱 다양한 상황에서의 세밀한 연구가 부족한 상태이다. 또한 이러한 타진방식 임플란트 안정성 측정기기는 실제 환자의 구강 내에서 HA의 높이와 타진각도의 다양한 변화에 따라 측정값이 영향을 받을 수 있을 것으로 추측되나 현재까지 이에 대한 연구는 거의 없는 실정이다.

따라서 이번 연구의 목적은 인조골에 동일한 조건으로 식립한 임플란트에 대하여 타진방식의 임플란트 안정성 측정기기인 Periotest와 AnyCheck을 사용하여 안정성 수치를 측정함에 있어서, HA의 높이와 타진각도의 변화에 따른 각 측정기기의 안정성 수치 차이를 조사하는 것이다.

재료 및 방법

상악 구치부의 해면골 평균 골밀도와, 평균 피질골 층을 재현한 인조골 블록(artificial bone block, Sawbones Pacific Research Laboratories, Vashon, WA, USA)을 이번 연구에 적합하도록 주문 제작하였다. 상악 구치부의 평균 해면골 밀도가 0.31 g/cm^{3}이기 때문에, 이를 재현하기 위해서 밀도가 0.32 g/cm^{3}인 블록을 사용했으며 피질골은 블록의 상단에 1 mm 두께의 에폭시 판(epoxy sheet)으로 재현하였다.[19] 블록은 길이 30 mm, 너비 30 mm, 높이 41 mm의 크기로 제작하였다.

60개의 CMI IS-II 임플란트(Neobiotech, Seoul, Korea)를 사용했으며 크기는 직경 4.0 mm, 길이 10.0 mm로 제조사의 표준 크기 임플란트를 사용했다 (Fig. 1A). Healing abutment (Neobiotech, Seoul, Korea)는 모두 직경이 4.5 mm였으며, 높이 2, 3, 4, 5 mm인 제품을 각각 15개씩 사용하였다. 식립 토크(insertion torque value, ITV) 측정을 위해 토크 라쳇(torque ratchet, Neobiotech, Seoul, Korea)을 사용했다.

표본 제작을 위해 고정용 바이스를 이용하여 인조골 블록의 장축이 지면과 수직이 되도록 고정시켰다. 핸드피스(INTRAsurg 300; KaVo Dental, Biberach, Germany)를 이용하여 인조골 블록의 정중앙에 임플란트를 식립했으며 ITV는 45 - 55 Ncm 범위의 통제된 힘으로 식립하였다 (Fig. 1A). 식립 방법은 제조사(Neobiotech, Seoul, Korea)에서 제공되는 표준 식립 방법을 따라 시행하였다. 식립 후 높이 2, 3, 4, 5 mm의 HA를 10 Ncm의 동일한 힘으로 체결하여 제작한 표본을 각각 15개씩 순서대로 그룹 1, 2, 3, 4로 분류하였다 (Table 1).[20]

Periotest 제품 중 2008년에 출시된 Periotest M을 사용하였다. 임플란트 장축이 지면과 수직인 상태에서 Periotest M을 임

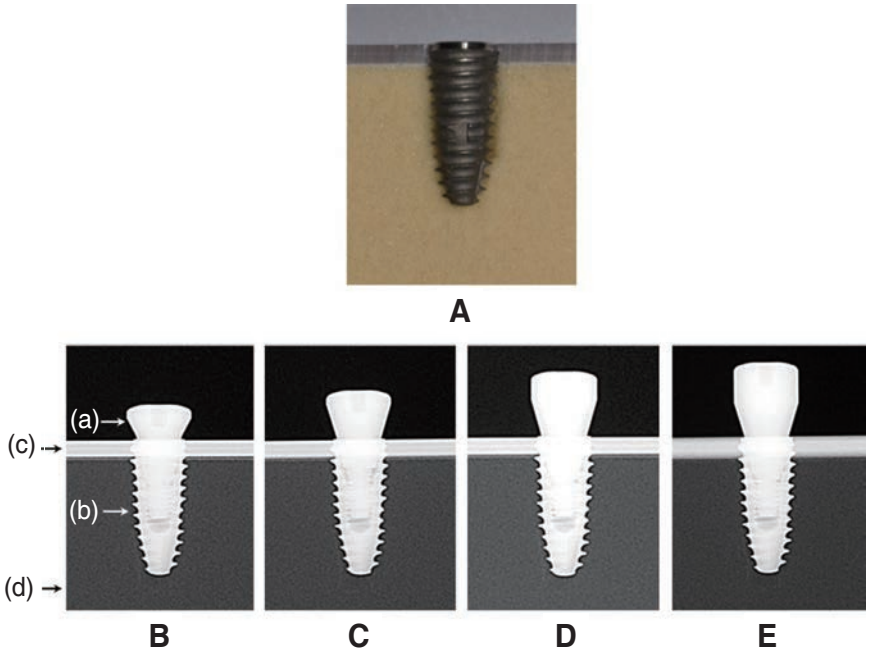

Fig. 1. (A) Cross-sectional view of CMI IS-II implant (4.0 mm diameter, 10.0 mm length) placed into artificial bone block. (B), (C), (D), (E) show radiographic images of specimens of 2, 3, 4, 5 mm healing abutments, respectively. In the radiographic images, (a) shows healing abutment and (b) shows implant. (c) shows cortical layer and (d) shows cancellous bone of artificial bone block.

Table 1. Specimen classification by healing abutment height

Group	1	2	3	4
Healing abutment height (mm)	2	3	4	5
Implant diameter (mm)	4.0	4.0	4.0	4.0
Implant length (mm)	10.0	10.0	10.0	10.0
Number of specimens	15	15	15	15

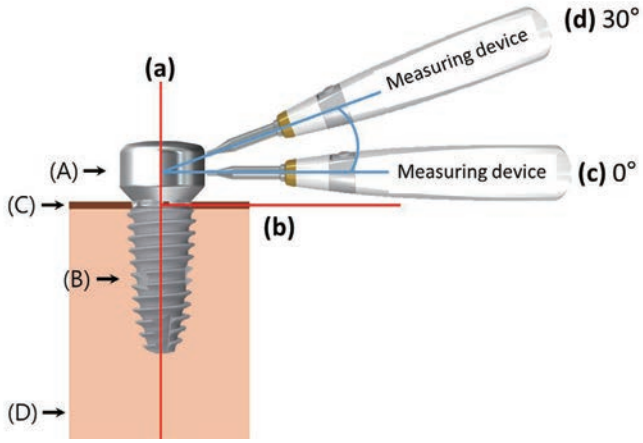

Fig. 2. Schematic representation of implant stability measurement. Long axis of implant (a) was perpendicular to horizontal plane (b). IST and PTV were measured at the angles of 0° (c) and 30° (d). Note that measurement angle of 0°(c) was parallel to the horizontal plane (b). (A) shows healing abutment and (B) shows implant. (C) shows cortical layer and (D) shows cancellous bone of artificial bone block.

플란트 장축과 수직으로, 즉 지면에 대하여 평행하게 위치시켜 측정하는 것을 기본 측정위치로 하고 있기 때문에 이번 연구에서는 지면과 평행한 각도를 0°로 규정하였다. 0° - 90°의 각도를 표시한 플라스틱 plate를 제작하여 지면과 수직이 되도록, 즉 0°를 나타내는 선이 지면과 평행하며 90°를 나타내는 선이 지면과 수직이 되도록 위치시켰다. 표본을 플라스틱 plate의 각도 기준점에 위치시킨 후, Periotest M을 0°와 30°선에 위치시켜 측정하였다. 0°로 측정 시 Periotest M을 지면에 평행하게, 가능한 측정 목표점에 근접하게 위치시킨 후 측정하였다.[21] 30°로 측정 시 Periotest M을 지면과 30°의 각도를 이루도록, 즉 임플란트 장축과 60°가 되도록 위치시킨 후 측정하였다 (Fig. 2). 측정 위치는 HA 측면의 가장 높은 지점에서 측정했으며, 각각의 임플란트에 대해 3 - 4번 반복 측정하여 같은 수치가 3번 측정되면 이 값을 각 임플란트 별 PTV로 정하였다.[22]

AnyCheck은 임플란트 장축이 지면과 수직인 상태에서 AnyCheck을 임플란트 장축과 수직으로, 즉 지면과 평행으로 위치시켜 측정하는 것이 기본 위치이므로 이번 연구에서는 지면과 평행한 각도를 0°로 정하였다. 0 - 90°의 각도를 표시한 플라스틱 plate를 지면과 수직이 되도록, 즉 0°를 나타내는 선이 지면

과 평행하며 90°를 나타내는 선이 지면과 수직이 되도록 위치시켰다. 표본을 플라스틱 plate의 각도 기준점에 위치시킨 후, AnyCheck을 0°와 30°선에 위치시켜 측정하였다. 0°로 측정 시, AnyCheck을 지면에 평행으로, 즉 임플란트 장축에 수직으로 가능한 측정점에 근접하게 위치시킨 후 측정하였다. 30°로 측정 시, AnyCheck을 지면과 30°의 각도를 이루도록, 즉 임플란트 장축과 60°를 이루도록 위치시킨 후 측정하였다 (Fig. 2). 측정 위치는 HA 측면의 가장 높은 지점에서 측정했으며, 각각의 임플란트에 대해 3 - 4번 반복 측정하여 같은 수치가 3번 측정되면 이 값을 각 임플란트 별 IST로 정하였다.

측정한 데이터에 대한 통계 분석을 시행하였으며, 모든 통계는 SPSS statistics 18.0 소프트웨어 프로그램(SPSS, Chicago, IL, USA)을 사용하여 분석했다. one-sample Kolmogorov-Smirnov test를 사용한 정규성 검정을 통해, ITV, PTV, IST 측정 데이터의 분포가 정규분포를 따르지 않음을 확인하여 비모수 통계 분석을 시행하였다. Kruskal-Wallis test를 시행하여 각 그룹의 ITV를 비교했으며, 2, 3, 4, 5 mm의 HA를 체결한 그룹 1, 2, 3, 4 간의 IST와 PTV를 측정한 값을 각각 비교하였다. 그룹 1, 2, 3, 4 간의 IST와 PTV 비교 시 Mann-Whitney U test를 이용하여 사후분석을 시행하였다. 또한 Mann-Whitney U test를 이용하여 동일한 HA 높이에서 IST와 PTV를 각각 0°와 30°로 측정한 값을 서로 비교하였다. $P < .05$이었을 때 통계적 유의성이 있다고 판단하였다.

결과

각 그룹의 ITV는 Kruskal-Wallis test를 시행했을 때 $P > .05$의 결과가 나왔기 때문에, 모든 그룹에서 통계적으로 유의한 차이가 없었다 (Table 2). ITV는 안정성 측정값에 영향을 미칠 수 있으므로 그룹 간 유의한 차이가 없도록 통제하였다.

AnyCheck을 사용하여 IST 측정 시 HA의 높이가 증가할수록 IST가 낮아짐을 확인할 수 있었다 (Fig. 3). 각도의 변화에 따른 차이는, 0°와 30°로 측정한 수치를 비교했을 때 30°로 측정한 IST가 더 높은 값을 나타냈으며 통계적으로 유의한 차이가 있었다 (Table 3, Fig. 4). 측정각도 0°와 30°에서 그룹 1과 2, 그룹 2와 3, 그룹 3과 4를 비교 시 통계적 유의차가 없었다 ($P > .05$). 그러나 그룹 1과 3, 그룹 1과 4, 그룹 2와 4를 비교 시 통계적 유의차가 있었다 ($P < .05$).

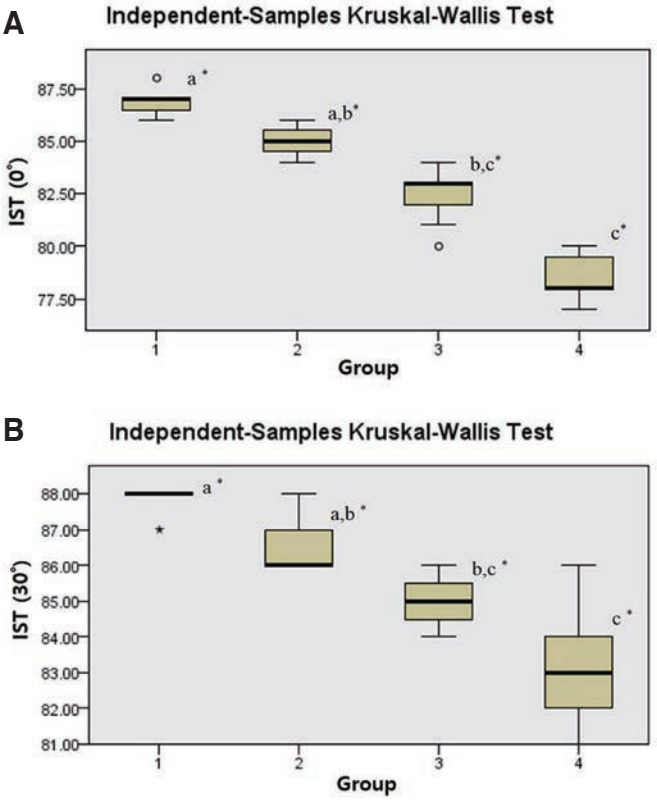

Fig. 3. (A) Results of Kruskal-Wallis test of implant stability test (IST) measured at the angle of 0° (n = 15). (B) Results of Kruskal-Wallis test of implant stability test (IST) measured at the angle of 30° (n = 15). Height of healing abutments (HA) were 2 mm, 3 mm, 4 mm and 5 mm in group 1, 2, 3 and 4, respectively.
*Different letters (a, b, c) indicate significant differences ($P < .05$).

Table 2. Mean values and standard deviations of ITV, IST, PTV

Group	1	2	3	4
ITV (Ncm)	50.8 ± 4.00	50.33 ± 3.52	50.7 ± 2.6	50.7 ± 2.6
IST (0°)	86.8 ± 0.56	84.93 ± 0.88	82.47 ± 0.99	78.53 ± 1.06
IST (30°)	87.93 ± 0.26	86.53 ± 0.64	84.93 ± 0.88	83.13 ± 1.25
PTV (0°)	-7.95 ± 0.13	-7.58 ± 0.33	-6.86 ± 0.49	-5.7 ± 0.36
PTV (30°)	-8	-8	-7.79 ± 0.28	-7.11 ± 0.35

IST; implant stability test, ITV; insertion torque value, PTV; Periotest value, Group 1; 2 mm healing abutment, Group 2; 3 mm healing abutment, Group 3; 4 mm healing abutment, Group 4; 5 mm healing abutment.

Table 3. Comparison of implant stability test (IST) and Periotest value (PTV) measured at the angles of 0° and 30° by Mann-Whitney U test

	0° (n = 15)	30° (n = 15)	*P* value[1)]
IST (group 1)	86.80 ± 0.56	87.93 ± 0.26	.000
IST (group 2)	84.93 ± 0.88	86.53 ± 0.64	.000
IST (group 3)	82.47 ± 0.99	84.93 ± 0.88	.000
IST (group 4)	78.53 ± 1.06	83.13 ± 1.25	.000
PTV (group 1)	-7.95 ± 0.13	-8	.539
PTV (group 2)	-7.58 ± 0.33	-8	.000
PTV (group 3)	-6.86 ± 0.49	-7.79 ± 0.28	.002
PTV (group 4)	-5.7 ± 0.36	-7.11 ± 0.35	.000

[1)] Exact significance is displayed for this test.
Group 1; 2 mm healing abutment, Group 2; 3 mm healing abutment, Group 3; 4 mm healing abutment, Group 4; 5 mm healing abutment.

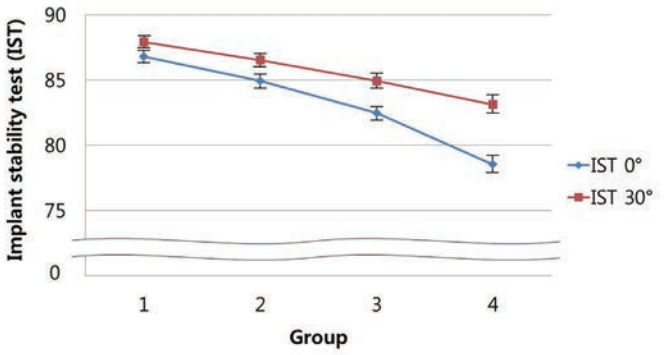

Fig. 4. Results of Mann-Whitney U test of implant stability test (IST) of each group measured at the angle of 0° and 30°. Height of healing abutments (HA) were 2 mm, 3 mm, 4 mm and 5 mm in group 1, 2, 3 and 4, respectively. IST measured at the angle of 30° was greater than IST measured at the angle of 0°. As the height of HA increased, difference between IST measured at the angle of 0° and 30° increased.
Group 1; 2 mm healing abutment, Group 2; 3 mm healing abutment, Group 3; 4 mm healing abutment, Group 4; 5 mm healing abutment.

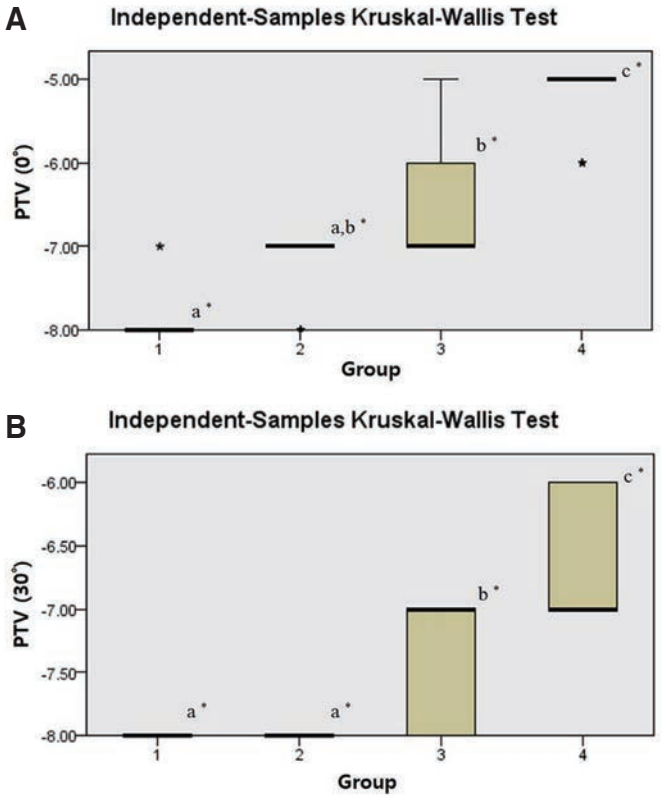

Fig. 5. (A) Results of Kruskal-Wallis test of Periotest value (PTV) measured at the angle of 0° (n = 15). (B) Results of Kruskal-Wallis test of Periotest value (PTV) measured at the angle of 30° (n = 15). Height of healing abutments (HA) were 2, 3, 4 and 5 mm in group 1, 2, 3 and 4, respectively.
*Different letters (a, b, c) indicate significant differences ($P < .05$).

Periotest M을 사용하여 PTV 측정 시, HA의 높이가 증가할수록 높은 PTV를 나타냈다 (Fig. 5). PTV는 커질수록 낮은 안정성을 의미하므로, 이는 HA의 높이가 증가할수록 안정성이 낮아지는 PTV가 측정된 것을 의미한다. 0°로 측정 시 그룹 1과 2, 그룹 2와 3을 비교했을 때는 통계적 유의차가 없었으며 그 외의 비교에서는 유의차가 있었다. 30°로 측정 시 그룹 1과 2를 비교했을 때는 통계적 유의차가 없었으며 그 외의 비교에서는 유의차가 있었다. 0°와 30°로 측정한 PTV를 비교 시 30°에서 더 낮은 PTV, 즉 더 안정성이 높은 수치를 나타냈다. 이 때 그룹 1에서는 통계적 유의차가 없었으며 그룹 2, 3, 4에서는 통계적 유의차가 있었다 (Table 3, Fig. 6).

Table 4. Guideline for evaluation of implant stability test (IST) according to healing abutment height

Standard + 3 mm	7 mm Healing abutment	IST +6
Standard + 2 mm	6 mm Healing abutment	IST +4
Standard + 1 mm	5 mm Healing abutment	IST +2
Standard	4 mm Healing abutment	IST
Standard – 1 mm	3 mm Healing abutment	IST -2
Standard – 2 mm	2 mm Healing abutment	IST -4
Standard – 3 mm	1 mm Healing abutment	IST -6

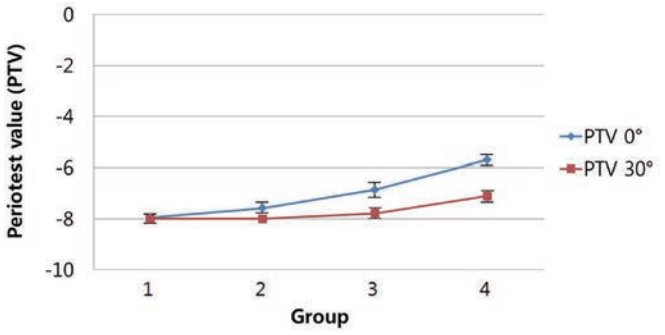

Fig. 6. Results of Mann-Whitney U test of Periotest value (PTV) of each group measured at the angle of 0° and 30°. Height of healing abutments (HA) were 2, 3, 4 and 5 mm in group 1, 2, 3 and 4, respectively. PTV measured at the angle of 30° was greater than PTV measured at the angle of 0°. As the height of HA increased, difference between PTV measured at the angle of 0° and 30° increased.
Group 1; 2 mm healing abutment, Group 2; 3 mm healing abutment, Group 3; 4 mm healing abutment, Group 4; 5 mm healing abutment.

고찰

AnyCheck과 Periotest M은 먼저 환자를 직립위로 앉도록 하여 임플란트 장축이 지면과 수직이 되도록 하고, 임플란트 장축에 수직이며 지면과 평행하도록 기기를 위치시켜 측정하는 것이 기본 위치이다. 따라서 이번 연구에서는 지면과 평행한 각도를 0°로 설정하였다. 악골 중 상악 구치부는 피질골이 얇고 해면골의 골밀도가 낮아 임플란트 실패율이 가장 높은 부위이다.[23-25] 임플란트의 안정성은 골밀도가 낮은 상악골에서 특히 중요시된다. 따라서 이번 연구에서는 상악 구치부를 재현하여 밀도가 0.32 g/cm^{3}인 인조골 블록을 주문 제작하여 사용하였다.[19]

ITV는 임플란트의 초기 안정성 평가에 중요한 요인 중 하나이며, 즉시부하와 초기기능력을 부여하기 위해서도 매우 중요하다.[26,27] 따라서 각 그룹 간 ITV가 통계적으로 유의한 차이가 있다면, 이에 따른 안정성 측정값의 차이 또한 통계적 분석에 포함시켜야 할 것이다. 그러나 이번 연구에서 ITV는 각 그룹 간 통계적 유의차가 없었다. 이는 임플란트 식립 시 그룹 간 유의차가 없도록 45 - 55 Ncm으로 통제했기 때문이며, 이번 연구의 통계 분석 시 ITV 변수를 제외하기 위한 것이었다. 그러나 그룹 내부의 수치간 편차가 존재하며, ITV를 45 - 55 Ncm으로 통제했음에도 데이터는 정규분포를 따르지 않았다.

IST는 HA의 높이가 높아질수록 더 낮은 IST를 나타냈다. 또한 0°보다 30°로 측정했을 때 더 높은 IST를 보였다. IST는 값이 높아질수록 더 높은 안정성을 의미하기 때문에 AnyCheck은 HA의 높이가 낮을수록, 지면을 기준으로 측정 기울기가 커질수록 더 높은 안정성 수치를 나타낸다고 할 수 있다. 측정각도 0°와 30°에서 그룹 1과 2, 그룹 2와 3, 그룹 3과 4를 비교 시 통계적으로 유의한 차이가 없었으나 그룹 1과 3, 그룹 1과 4, 그룹 2와 4를 비교 시 통계적 유의차가 있었다. 이는 HA 높이 1mm 차이는 IST에서 유의차가 없으나, 2 mm 이상 차이가 나는 경우 IST에서 유의차가 존재한다는 것을 의미한다. 제조사에서 제공하는 AnyCheck 설명서에 따르면, HA의 높이가 1 mm 높아지면 IST가 2만큼 낮아진다고 하였다 (Table 4). 이번 연구에서, 30°로 측정 시 HA가 1 mm 높아지면 IST 1.4 - 1.8의 차이가 있었으며 이는 설명서와 유사한 결과였다. 그러나 0°로 측정 시 HA의 높이가 1 mm씩 높아질수록 IST 차이도 1.9 - 4로 더 커지는 것을 확인할 수 있었다. 즉, 0°로 측정한 경우가 30°로 측정했을 때보다 HA 높이에 따른 타진 시 동요도의 차이가 더 크다는 것을 확인할 수 있다. 측정각도에 따른 차이는 IST 1.1 - 4.6의 차이가 났으며 HA의 높이가 높아질수록 더 커졌고, 모든 그룹에서 통계적 유의차가 있었다 (Table 3, Fig. 4).

PTV는 동일한 임플란트에서도 다양한 요인에 의해 측정값이 달라질 수 있다. Gomez-Roman과 Lukas[28]의 연구에 따르면 HA를 체결했을 때와 지대주를 체결했을 때의 측정값은 PTV 3.5의 차이가 발생하며, 지대주만 체결했을 때와 크라운까지 장착했을 때의 측정값은 PTV 1.7의 차이가 있다고 하였다. 그러나 HA, 지대주, 크라운의 구체적인 높이에 대한 측정이 이루어지지 않아서 측정 대상의 높이에 따른 차이가 분석되지 않은 한계점이 있었다. Faulkner 등[14]은 Periotest가 충격을 가하는 위치에 따라서 PTV 차이가 있으며, 1 mm의 위치 차이에서 PTV가 1 - 2 정도 변할 수 있다고 보고하였다. 또한 같은 위치에서 측정했을 때 측정각도에 따라서 PTV 2.5 - 4.0의 차이가 발생할 수 있다고 보고하였다. 이번 연구에서 PTV의 경우 HA의 높이가 높아질수록 더 높은 PTV를 보였으며 0°보다 30°로 측정했을 때 더 낮은 PTV를 나타냈다. 이는 AnyCheck과 마찬가지로 HA의 높이가 낮을수록, 지면을 기준으로 측정 기울기가 커질수록 더 안정성이 높은 PTV를 나타낸다고 할 수 있다. 그러나 0°로 측정 시 그룹 1과 2, 그룹 2와 3을 비교했을 때는 통계적 유의차가 없었으며 그 외의 비교에서는 유의차가 있었다. 이는 HA 높이가 3 mm보다 높거나, 높이 차이가 2 mm 이상일 경우에만 PTV 차이가 있었다는 것을 의미한다. 30° 측정 시 그룹 1과 2의 비교에서는 통계적 유의차가 없었고 그 외의 비교에서는 유의차가 있었는데, 이는 HA

높이 2 mm와 3 mm 사이에만 PTV 차이가 없으며 그 외의 HA 높이 차이에서는 PTV 차이가 있었다는 것을 의미한다. 이번 연구에서 각 그룹의 PTV 차이를 계산한 결과, 1 mm의 높이 차이에서 PTV가 0.21 - 1.16의 변화를 나타냈다. 같은 위치에서 측정한 경우 측정각도에 따라서 PTV 0 - 1.41의 차이가 발생하였으며 HA 높이가 높아질수록 PTV 차이가 커졌다 (Table 3, Fig. 6). 기존 연구결과와 비교하였을 때 HA 높이와 측정각도 변화에 따른 PTV의 차이가 더 작은 것을 확인할 수 있다.

위와 같은 결과를 통해, 타진 방식의 임플란트 안정성 측정기기는 HA의 높이가 낮아질수록, 측정각도가 커질수록 더 안정성이 높은 측정값을 나타낸다고 예측할 수 있다. HA의 높이가 높아지는 경우, 안정성의 근원이 되는 임플란트와의 거리가 멀어지기 때문에 동요도가 미세하게 증가하여 PTV와 IST의 차이가 나타나는 것으로 생각된다. 임플란트를 식립하는 실제 환자의 무치악부위 상태에 따라서, 다양한 높이의 HA를 체결할 수 있다. 이 때 타진 방식으로 측정할 경우 안정성 측정값이 HA 높이에 따라 다르게 나타나므로, 이를 고려하여 판단해야 할 것이다.

안정성 측정각도가 커지는 경우, 임플란트 장축에 대해 수직으로 측정했을 때와 다르게 타진 시의 힘의 벡터가 임플란트 장축과 평행한 방향과, 장축에 대해 수직인 방향으로 나뉘게 된다. 동요도는 임플란트 장축에 수직인 방향으로 발생하는 움직임이기 때문에, 타진각도가 달라지면 동요도가 달라지게 되어 PTV와 IST의 차이가 나타나는 것으로 생각할 수 있다. 측정기기의 각도에 따른 PTV와 IST의 변화는 임상에서 중요하다. 임상에서 환자의 자세 또는 연조직 등의 제한으로 측정기기를 임플란트 장축에 수직으로 위치시키지 못 할 경우가 발생할 수 있다. 측정각도가 커짐으로써 더 높은 안정성 수치가 나올 경우 단순히 실제 임플란트의 안정성이 높다고 판단하는 것이 아니라, 측정 조건에 따른 수치의 변화를 고려하는 것이 바람직하다.

결론

이번 연구의 결과를 통해, 아래와 같은 결론을 내릴 수 있다.

타진방식 임플란트 안정성 측정기기인 AnyCheck과 Periotest M은 임플란트를 동일한 토크로 식립했을 때,

1. Healing abutment의 높이가 증가할수록 안정성 수치가 낮게 측정되었다.
2. 임플란트 장축에 대해 수직이며 지면에 대해 평행한 각도인 0°로 측정한 경우가 지면에 대해 30°로 측정했을 때보다 안정성 수치가 더 낮게 측정되었다.
3. 따라서 임플란트의 안정성을 타진방식으로 측정할 때, healing abutment 높이와 타진각도의 변화에 따른 차이를 고려하여 측정해야 표준화된 평가를 할 수 있으며, 이에 대한 더욱 세밀한 사용법을 인지할 필요가 있다고 사료되었다.

ORCID

Yang-Hoon Park *https://orcid.org/0000-0001-6786-1380*
Richard Leesungbok *https://orcid.org/0000-0002-8381-723X*
Suk-Won Lee *https://orcid.org/0000-0003-2726-3567*
Janghyun Paek *https://orcid.org/0000-0002-1286-3140*
Jeong-Yol Lee *https://orcid.org/0000-0003-3079-0376*

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ORIGINAL ARTICLE

임플란트 healing abutment 높이와 타진각도에 따른 타진방식 임플란트 안정성 측정기기의 수치 차이

박양훈[1] · 이성복[1]* · 이석원[1] · 백장현[2] · 이정열[3]

[1]강동경희대학교 치과병원 생체재료 보철과, [2]경희대학교 치과대학 치과보철학교실, [3]고려대학교 구로병원 임상치의학 연구소

목적: 인조골에 동일한 조건으로 식립한 임플란트에 대하여 타진방식의 임플란트 안정성 측정기기인 Periotest와 AnyCheck을 사용하여 안정성 수치를 측정함에 있어서, healing abutment의 높이와 타진각도의 변화에 따른 각 측정기기의 안정성 수치 차이를 조사하는 것이다.

재료 및 방법: 총 60개의 임플란트를 주문제작한 인조골 블록에 식립하고 2, 3, 4, 5 mm 높이의 healing abutment를 각각 15개씩 네 그룹으로 나누어 체결하였으며, 각각 식립 토크, implant stability test, Periotest value를 측정했다. 임플란트 식립 시 45 - 55 Ncm의 토크를 유지하였다. 임플란트 장축에 수직인 지면을 기준으로, implant stability test는 AnyCheck을 사용하여 0°, 30°의 기울기로 측정했으며 Periotest value는 Periotest M을 사용하여 0°, 30°의 기울기로 측정하였다. 측정값은 통계적으로 비교 분석하였다.

결과: 식립 토크는 그룹 간 통계적 유의차가 없었다. AnyCheck과 Periotest M으로 측정했을 때, healing abutment의 높이가 증가할수록 안정성 수치가 낮게 측정되었다. 또한 AnyCheck과 Periotest M을 0°와 30° 기울기로 측정 시 0°로 측정한 그룹에서 안정성 수치가 더 낮게 측정되었다.

결론: 임플란트의 안정성 수치를 타진방식으로 측정할 때에는 healing abutment 높이와 타진각도의 변화에 따른 차이를 고려하여 측정해야 표준화된 평가를 할 수 있으며, 이에 대한 더욱 세밀한 사용법을 인지할 필요가 있다고 사료되었다. *(대한치과보철학회지 2018;56:278-86)*

주요단어: 임플란트 안정성; AnyCheck; Periotest; Implant stability test; Periotest value; 식립 토크

*교신저자: 이성복
05278 서울 강동구 동남로 892 강동경희대학교 치과병원 생체재료 보철과
02 440 7520: e-mail, sbykmw@yahoo.co.kr
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The macrosomic-at-birth individuals who at the time of birth had a well-balanced development (Subgroup I) had more than three times higher percentage of premature eruption of deciduous or permanent teeth, relative to the comparison group. Such individuals were significantly more likely to report a periodic or persistent dry mouth, periodic or persistent gum bleeding, and bad breath.

The macrosomic-at-birth individuals who had a large body length and a relatively low body weight at birth (Subgroup II) have reported significantly more complaints about hypertension. They are sick for a long time and take medicines more often. They are significantly more likely than persons in the comparison group to have delayed terms of deciduous or permanent teeth eruption, periodic or permanent bleeding of the gums, and more often complain about pain or crunching in the temporomandibular joints.

The macrosomic-at-birth persons, who at the time of birth had a large body length and intrauterine obesity (Subgroup III), have the highest percentage of cases of complaints about teeth hypersensitivity to various stimuli.

The macrosomic-at-birth persons, who at the time of birth had an average body length and intrauterine obesity (Subgroup IV) on average, were more likely to be sick for a long time more often, had a higher percentage of cases of allergic diseases, and were more often than the persons in the comparison group born not from the first labor. The individuals in this subgroup were significantly more likely to have malocclusions, and they had a tendency to increase the number of complaints about the teeth hypersensitivity.

Key words: questionnaire, fetal macrosomia, oral pathology, somatic pathology.

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Добровольська О. В.

ВИЗНАЧЕННЯ СТАБІЛЬНОСТІ ІМПЛАНТАТІВ ЯК ОБ'ЄКТИВНИЙ МЕТОД ПРОГНОЗУВАННЯ ТА ОЦІНКИ ЕФЕКТИВНОСТІ ЛІКУВАННЯ В ДЕНТАЛЬНІЙ ІМПЛАНТОЛОГІЇ

Українська медична стоматологічна академія (м. Полтава)

oxana.dobr88@gmail.com

Зв'язок публікації з плановими науково-дослідними роботами. Тематика публікації обумовлена ініціативною темою науково-дослідної роботи кафедри ортопедичної стоматології з імплантологією «Нові технології, сучасні і удосконалені зуботехнічні матеріали в реабілітації хворих з патологією зубо-щелепної системи» (державна реєстрація № 0111U006304).

Вступ. Успіх відновлювальних операцій з використанням дентальних імплантатів залежить від багатьох факторів, в тому числі від науково обґрунтованого вибору моменту початку навантаження дентальних імплантатів і адекватної оцінки їх здатності нести функціональне навантаження. Лікарю – стоматологу – ортопеду необхідна достовірна інформація про ступінь остеоінтеграції, знання динаміки цього процесу, особливо на початковій стадії, а також методику для об'єктивної оцінки якості проведеної операції дентальної імплантації [1,2,3].

На сучасному етапі розвитку дентальної імплантології основними розповсюдженими методами оцінки стану остеоінтеграції внутрішньокісткових імплантатів, разом з клінічними, є рентгенологічний, торк-тестування за допомогою динамометричного ключа, періотестометрія з використання прибору Periotest (Gulden, Німеччина), частотно-резонансний аналіз стабільності імплантатів з використанням прибора Osstell-mentor (Integration Diagnostics, Швеція) [4,5,6].

Метод періотестометрії запропоновано W. Shulte у 1985 році для визначення оцінки стану періодонту природних зубів. Тільки згодом пристрій почав використовуватись для оцінки міцності кріплення дентальних імплантатів. Методика полягає у кореляції між щільністю кісткової тканини в ділянці зубних імплантатів та її демпферними властивостями при ударному навантаженні [7].

Останнім часом для оцінювання готовності дентальних імплантатів до функціонального навантаження користуються прибором Osstell Mentor [8]. У 1997 році професор N. Meredith (Університет Лідса, Великобританія) звернув увагу на зв'язок між резонансною частотою вимушених коливань дентальних імплантатів та жорсткістю кісткової тканини [9,10].

Показання приладів, засновані на динамічному впливі, – це відповідна реакція динамічної системи «імплантат – кісткова тканина» на одне з можливих малих збурень (удар, періодичну силу або будь-яке інше), що вносяться при вимірюванні. Кожен з цих приладів дає кількісну оцінку міцності кріплення дентальних імплантатів. В приладах Periotest – це коефіцієнти демпфування, в приладах Osstell Mentor – коефіцієнт стабільності. Необхідно відзначити, що обидва прилади дають оцінку міцності кріплення дентальних імплантатів на підставі непрямих ознак і в своїх умовних одиницях, фізичний зміст яких неясний. Техніка частно-резонансного аналізу не завжди дозволяє точно виявити рухомі імплантати. Одним з пояснень цієї неточності може бути сама природа цього аналізу, який вимірює стабільність імплантатів в залежності від жорсткості системи. Клінічно рухомі імплантати мають надзвичайно низьку жорсткість та не дають системі визначить первинну резонансну частоту. В цьому випадку коефіцієнт стабільності виявляється дуже високим, тому що визначається за даними вторинної резонансної частоти, що призводить до недостатньо об'єктивних вимірів та недостовірних прогнозів [8,11,12,13].

В своїй роботі ми використовували прибор AnyCheck виробництва Південної Кореї для вимірю-

вання стабільності імплантатів за допомогою ударного імпульсу. Деякі аспекти використання пристрою AnyCheck вивчено недостатньо, а саме мало відомостей про динаміку показників стабільності імплантатів в ранні та віддалені строки функціонування імплантатів в різних клінічних випадках. Також достеменно не відомо, чи впливає верифікація факту первинної стабільності, яка визначається за допомогою даного пристрою, на прогноз функціонування внутришньокісткової опори.

Мета дослідження. Порівняти результати стабільності внутришньокісткових імплантатів при безпосередньому та відстроченому навантаженні, на різних етапах імплантації: на початку навантаження, через – півроку та через рік функціонування протезних конструкцій за допомогою пристрою Any Check.

Об'єкт і методи дослідження. Протягом 12 місяців проведено динамічне спостереження за станом 94 дентальних імплантатів системи Neobiotech (Південна Корея), які встановлено 52 пацієнтам з частковою відсутністю зубів. Для поставлених цілей дослідження сформовано наступні групи. До першої групи надійшли хворі (11 осіб), яким проведено безпосереднє навантаження 19 імплантатів на верхній щелепі поодинокими або об'єднаними коронками у фронтальному та боковому відділах. До другої групи надійшли пацієнти (14 осіб), яким проведено безпосереднє навантаження 23 імплантатів на нижній щелепі поодинокими або об'єднаними коронками у фронтальному та боковому відділах. До третьої групи надійшли пацієнти (14 осіб), яким проведено відстрочене навантаження 28 імплантатів на верхній щелепі поодинокими або об'єднаними коронками у фронтальному та боковому відділах. До четвертої групи надійшли пацієнти (13 осіб), яким проведено відстрочене навантаження 24 імплантатів на нижній щелепі поодинокими або об'єднаними коронками у фронтальному та боковому відділах. В третій та четвертій групі навантаження відбувалося в загальноприйняті терміни (2-3 місяця на нижній щелепі та 4-5 місяців на верхній).

Всі пацієнти не мали загальних протипоказань до імплантації. З дослідження були виключені пацієнти з наступними факторами ризику: важка ступінь бруксизму, куріння понад 20 сигарет за добу та надмірне вживання алкоголю, локалізована променева терапія порожнини рота, імунодепресивні стани, прийом кортикостероїдів, вагітність, запальні і аутоімунні захворювання порожнини рота, погана гігієна порожнини рота.

Ключовим фактором для відбору пацієнтів до I та II груп, яким проводилась імплантація та негайне навантаження, було досягнення оптимальної первинної стабільності не менше 40-50 Нсм (торктестування). На верхній щелепі досягнути доброї первинної стабільності, де кісткова тканина 3-го та 4-го типу, можливо за рахунок особливостей макродизайну імплантата, а саме завдяки сильно виступаючих витків різьби і великої площі поверхні імплантату. У своїй клінічній роботі ми віддали перевагу розбірним імплантатам системи «Neobiotech», Південна Корея. Ці імплантати коренеподібної форми з унікальним поєднанням конструкційних особливостей призначені для встановлення в різних типах кістки із застосуванням мітчиків. Завдяки наявності триходового мікрорізьблення забезпечується зниження резорбції маргінальної кістки і збільшується площа контакту кістка – імплантат. Макро – і мікропористість внутрішньокісткової частини імплантата забезпечують необхідні умови для остеоінтеграції. Зворотний кут, розташований на різальних витках основного різьблення, сприяє атравматичному введенню імплантата. Глибоко врізаючись в губчастий шар кістки, плоске закруглене різьблення дозволяє домогтися максимальної площі контакту поверхні імплантату з кістковою тканиною. З'єднання імплантат – абатмент відбувається за рахунок сполучення конуса і внутрішнього шестигранника, що дозволяє оптимально розподілити осьові й ротаційні сили при жувальних навантаженнях.

Виготовлення тимчасової ортопедичної конструкції здійснювали декількома способами: виготовлення тимчасових коронок безпосередньо в порожнині рота по силіконовому шаблону, перебазування заздалегідь виготовлених коронок, зняття відбитків відразу після операції з наступною фіксацією протеза через кілька годин.

Метод обстеження хворого до імплантації та на етапах диспансерного контролю включали клініко-рентгенологічні методи.

При первинному зверненні проводилось анкетування хворих з метою визначення загальносоматичних протипоказань, огляд та інструментальне дослідження порожнини рота та зубних рядів. Отримували відбитки та відливали діагностичні моделі. Рівень гігієни порожнини рота оцінювали за гігієнічним індексом Green, Vermillion, визнавали площу м'якого наліту на коронковій частині зубів. Стан слизової оболонки визначали за індексом Silness, HiLoe [14,15].

Рентгенологічне обстеження включало ортопантомографію, прицільну внутришньоротову рентгенографію та комп'ютерну томографію.

Постановка імплантатів проводилась під місцевим знеболенням.

Клініко-рентенологічне дослідження стану імплантатів доповняли аналізом стабільності імплантатів за допомогою пристрою AnyCheck від NeoBiotech. Він не впливає на стійкість імплантата і не викликає інших ускладнень.

AnyCheck це пристрій, який визначає міцність контакту альвеолярного відростку з імплантатом за допомогою ударного імпульсу. Він простий у використанні за рахунок невеликого та легкого дизайну корпусу, крім того зняття показань можливо за наявності формувачів ясен на імплантатах різних систем, отже немає необхідності придбання штифтів SmartPeg як для Osstell ISQ. Тривалість усього циклу вимірювання становила 3 сек.

Перший цикл – порушення механічного ударного імпульсу і передача його на бойок. Сила ударного імпульсу зменшена на 30% в порівнянні з приладом Periotest. Другий цикл – прийом відкликання механічної системи і передача інформації на мікропроцесор. Під час роботи пристрою наконечник задає для імплантата певний механічний імпульс, а потім реєструє його відповідні акустичні коливання, які відображаються на LCD – екрані пристрою. Ступінь остеоінтеграції визначається в діапазоні від 30 до

85 одиниць і позначається як IST (Initial Stability Test) аналогічно шкалі ISQ.

Найбільшу перевагу отримували, вимірюючи стабільність кількох імплантатів одночасно. У випадку недостатньої остеоінтеграції імплантатів, робота пристрою автоматично призупиняється після двох ударних імпульсів. В інших випадках, кількість ударних імпульсів дорівнювало шести.

Чим більший показник був визначений для кожного окремого імплантата, тим кращий стан остеоінтеграції. Для остеоінтегрованих імплантатів оптимальні значення величин змінюються в межах від 65 до 85 одиниць. Виміряне значення вказується червоним кольором при показниках 30-59, помаранчевим 60-64, зеленим 65-85 одиниць.

Індексна оцінка стану імплантатів включала критерії ефективності імплантації за Smith, Zarb (1987) [15]. Критерії ефективності за Smith-Zarb передбачають:

- нерухомість окремого імплантату при клінічному дослідженні,
- відсутність резорбції кісткової тканини навколо імплантата по даним рентгенографії,
- відсутність резорбції кісткової тканини в пришийковій ділянці після першого року навантаження,
- відсутність болю, дискомфорту, інфікування в ділянці імплантату.

Обстеження тканин навколо імплантатів проводили на момент встановлення імплантатів, на момент функціонального навантаження ортопедичними конструкціями, а потім через 6 та 12 місяців.

Результати дослідження та їх обговорення. При безпосередньому навантаженні внутришньокісткових імплантатів вихідні значення стабільності імплантатів в I та II групах в середньому становили за даними AnyCheck 66,8+4,7 IST. Стабільність імплантатів на верхній щелепі була нижче 65,6+4,2 IST, у порівнянні з нижньою щелепою 68,0+5,1 IST. Незначно нижче вихідні показники при постановці імплантатів у боковому відділі у порівнянні з фронтальним відповідно 67,4+5,1 IST та 64,2+5,5 IST на верхній щелепі, та 68,2+3,6 IST і 67,8+4,8 IST на нижній щелепі.

Середні показники тестування імплантатів в III та IV групах, були менші у порівнянні з I та II групами з безпосереднім навантаженням, та складали в середньому 63,1+3,9 IST. Це відбулося за рахунок того, що в I та II групи було обрано імплантати з досить високим значенням IST, а імплантати з меншими показниками стабільності надійшли до групи з відстроченим навантаженням. На верхній щелепі вихідні показники стабільності були нижчі, чим на нижній, відповідно 61,9+3,4 IST і 64,3+4,4 IST.

У фронтальному відділі стабільність імплантатів в III та IV групах вище у порівнянні з боковим відділом як на нижній так і на верхній, на нижній щелепі відповідно у фронтальному та боковому відділі 65,1+4,9 і 63,5+3,9 IST; і на верхній щелепі 60,9+3,7 IST і 62,9+3,1 IST.

На момент розкриття імплантатів в групах III та IV, встановлення формувачів ясеневої манжетки значення стабільності імплантатів збільшилось у середньому до 68,6+4,6 IST на верхній щелепі, і до 71,0+5,5 IST на нижній щелепі. У фронтальному відділі верхньої щелепи до 69,1+4,3 IST; у боковому відділі верхньої щелепи до 68,0+3;7 IST, у фронтальному відділі нижньої щелепи до 71,2+5,8 IST, у боковому відділі нижньої щелепи – до 70,8+5,2 IST.

Після 6 місяців навантаження показники стабільності імплантатів при відстроченому навантаженні у III та IV групах мають тенденцію до збільшення. У фронтальному відділі верхньої щелепи стабільність збільшувалась до 72,4+4,0 IST, у боковому відділі до 70,9+4,2 IST; у фронтальному відділі нижньої щелепи до 75,1+3,5 IST, у боковому відділі до 72,2+4,2 IST; в цілому на верхній щелепі до 71,65+4,0 IST, по нижній щелепі до 73,65+3,8 IST; в середньому по обом щелепам до 72,65+4 IST.

Через 12 місяців функціонального навантаження у III та IV групах збільшення стабільності імплантатів досягнуло наступних показників: на верхній щелепі до 75,3+3,5 IST, відповідно у фронтальному відділі верхньої щелепи до 75,8+3,8 IST, у боковому відділі верхньої щелепи 74,7+3,9 IST; на нижній щелепі показники стабільності доходили до 79,5+3,1 IST, відповідно у фронтальному відділі нижньої щелепи 80,1+3,0 IST; у боковому відділі нижньої щелепи 78,3+ 3,1 IST. В цілому по верхній та нижній щелепі до 71,8+3,1 IST. Всі імплантати були інтегровані.

У I та II групах при безпосередньому навантаженні імплантатів максимальні показники стабільності імплантатів протягом 6 місяців збільшились в середньому на верхній щелепі до 69,9+3,5 IST, відповідно у фронтальній ділянці верхньої щелепи до 70,8+3,5 IST; у боковому відділі верхньої щелепи до 69,1+3,4 IST; на нижній щелепі в середньому становили 71,3+3,0 IST, відповідно у фронтальній ділянці нижньої щелепи до 72,1+2,9 IST, у боковій ділянці до 70,5+3,1 IST. Через 12 місяців функціонального навантаження показники суттєво не змінились, але досягли максимального значення: на верхній щелепі 74,3+2,1 IST та 75,3 +1,3 IST. У двох пацієнтів мали значне зменшення показників стабільності IST імплантатів (4 імплантата) до 35 одиниць, що вказує на перевантаження. Такі імплантати було видалено.

Таким чином, при порівняні показників стабільності імплантатів в різних відділах верхньої та нижньої щелепи та при різних протоколах навантаження імплантатів можна зробити наступні **висновки:**

- у всіх клінічних групах максимальне значення стабільності імплантатів реєструється через один рік. Цей факт доведено у статистично достовірному збільшенні ($p<0,05$) стабільності імплантата в обох групах;
- вихідні значення стабільності імплантатів у середньому по обом щелепам не мають достовірної різниці при безпосередньому або відстроченому навантаженні 66,8+4,7 IST проти 63,1+3,9 ($p >0,05$);
- вихідні показники стабільності імплантатів на верхній щелепі нижче ніж на нижній щелепі в 65,6+3,8 і 68,0+4,8 IST (($p<0,05$));
- зниження коефіцієнта стабільності імплантатів під час навантаження вказує на наявність перевантаження даного імплантата;
- однак використовувати даний пристрій для верифікації факту первинної стабільності недоцільно, оскільки показники приладу не пов'язані з прогнозом функціонування внутришньокісткової опори. Це свідчить про те, що навіть при недостатній первинній механічній фіксації імплантата при відстроченому навантаженні можна очікувати на поліпшення стабільності імплантата завдяки біологічній фазі остеоінтеграції.

Отже пристрій AnyCheck допомагає провести контроль остеоінтеграції імплантата під час фази імплантації, а також після ортопедичного лікування, з метою виявлення негативних змін на ранній стадії.

Перспективи подальших досліджень. В подальшому ми плануємо досліджувати стабільність імплантатів за допомогою пристрою AnyCheck на етапах ортопедичної реабілітації. Чи впливає втрата кортикальної речовини альвеолярної кістки, яка визначається за допомогою рентген-діагностики, на показники стабільності імплантата належить з'ясувати в процесі лікування.

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ВИЗНАЧЕННЯ СТАБІЛЬНОСТІ ІМПЛАНТАТІВ ЯК ОБ'ЄКТИВНИЙ МЕТОД ПРОГНОЗУВАННЯ ТА ОЦІНКИ ЕФЕКТИВНОСТІ ЛІКУВАННЯ В ДЕНТАЛЬНІЙ ІМПЛАНТОЛОГІЇ

Добровольська О. В.

Резюме. Стаття присвячена визначенню механічної стабільності ендосальних дентальних імплантатів на етапах остеоінтеграції в залежності від строків функціонального навантаження. Механічна стабільність імплантата є важливим показником нормальної остеоінтеграції. Стабільність імплантатів визначали за допомогою пристрою AnyCheck. Проведено порівняння показників стабільності імплантатів в різних відділах верхньої та нижньої щелепи та при різних протоколах навантаження імплантатів: безпосереднє та відстрочене навантаження.

Ключові слова: механічна стабільність дентальних імплантатів, частотно-резонансний аналіз, періотестометрія, остеоінтеграція.

ОПРЕДЕЛЕНИЕ СТАБИЛЬНОСТИ ИМПЛАНТАТОВ КАК ОБЪЕКТИВНЫЙ МЕТОД ПРОГНОЗИРОВАНИЯ И ОЦЕНКИ ЭФФЕКТИВНОСТИ ЛЕЧЕНИЯ В ДЕНТАЛЬНОЙ ИМПЛАНТОЛОГИИ

Добровольская О. В.

Резюме. Статья посвящена определению механической стабильности эндосальных дентальных имплантатов на этапах остеоинтеграции в зависимости от сроков функциональной нагрузки. Механическая стабильность имплантата является важным показателем нормальной остеоинтеграции. Стабильность имплантатов определяли с помощью прибора AnyCheck. Проведено сравнение показателей стабильности имплантатов в различных отделах верхней и нижней челюсти и при различных протоколах нагрузки имплантатов: непосредственная и отсроченная нагрузка.

Ключевые слова: механическая стабильность дентальных имплантатов, частотно-резонансный анализ, периотестоматрия, остеоинтеграция.

DETERMINATION OF STABILITY OF IMPLANTS AS AN OBJECTIVE METHOD FOR PREDICTING AND EVALUATING EFFICIENCY TREATMENT IN DENTAL IMPLANTOLOGY

Dobrovolskaya O. V.

Abstract. This work is dedicated to stability of the dental implant in stages of osteointegration by the method of resonance frequency analysis. Mechanical stability of implant is an important parameter of a normal osteointegration. Implant stability was determined by the analysis method AnyCheck.

The success or failure of bone implants has been demonstrated to be related to the quality of the bone–implant interface which provides the support to transfer loads from the implant to the bone. New bone apposition at the bone–implant interface requires a good primary implant stability with limited micromovements at the interface;

this primary stability is provided by the mechanical engagement of the implant in the bone. In facts, relative displacements between the bone and the implant above 50–150 μm can lead to fibrous bone formation, providing a very poor long-term secondary stability; secondary stability is the biologic stability provided through bone regeneration and remodeling. The necessity of limiting these so-called 'micromovements' has induced the setup of follow-up protocols where functional loads are applied after a prescribed period of time (3–6 months, according to the original protocol).

As a general rule, devices not requiring an additional element in contact with the abutment are considered to be safer: the Periotest, AnyCheck belong to this category, while the Osstell requires screwing the magnetic peg on the top of the abutment with 10 Ncm torque, and this might affect the bone–implant interface at the early healing stage. On the other hand, no-contact device results are hampered by a lack of repeatability, since small deviations in the location of the impact point result in significant variations of results.

When comparing the stability of implants in different departments of the upper and lower jaw and different protocols of loading the implants, we can draw the following *conclusions:*

- the maximum value of implant stability is recorded after one year in all clinical groups. This fact was proved in a statistically significant increase ($p < 0.05$) of implant stability in both groups;
- the initial values of the stability of the implants on the average for both jaws do not have a significant difference with direct or delayed loading 66,8 + 4,7 IST against 63,1 +3,9 ($p > 0,05$);
- a decrease in the implant stability factor during loading indicates that the implant is overloaded;
- however, it is not advisable to use this device to verify the primary stability fact, as the instrument's performance is not related to the prognosis of intraosseous support. This indicates that even with insufficient initial mechanical fixation of the implant with delayed loading, one can expect to improve the stability of the implant due to the biological phase of osteointegration.

Therefore, AnyCheck helps to control the implant osteointegration during the implantation phase and after orthopedic treatment, in order to detect negative changes at an early stage.

Key words: mechanical stability of dental implants, resonance-frequency analysis, osteointegration.

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Іваницька О. С., Іваницький І. О., Рибалов О. В., Гаврильєв В. М., Бойко І. В.

УСУНЕННЯ ГІПЕРЧУТЛИВОСТІ ЗУБІВ: ПОЄДНАННЯ КОНСЕРВАТИВНОГО ТА ХІРУРГІЧНОГО ЛІКУВАННЯ

Українська медична стоматологічна академія (м. Полтава)

ivanytskaos@ukr.net

Зв'язок публікації з плановими науково-дослідними роботами. Стаття є фрагментом науково-дослідної роботи кафедри хірургічної стоматології та щелепно-лицевої хірургії з пластичною та реконструктивною хірургією голови та шиї Українська медична стоматологічна академія (м. Полтава) за темою «Діагностика, хірургічне та медикаментозне лікування пацієнтів з травмами, дефектами та деформаціями тканин, запальними процесами щелепно-лицевої ділянки (державний реєстраційний № 0119U102862).

Вступ. У сучасних умовах у більшості країн Європи значно збільшилась кількість звернень до лікарів-стоматологів з приводу підвищеної чутливості зубів [1,2]. Необхідно зазначити, що актуальність вивчення проблеми гіперчутливості зубів (ГЗ) пов'язана не тільки з високою частотою та мультифакторністю ґенеза даного захворювання, а й тим, що, хоча віковий діапазон таких пацієнтів є достатньо широким, та все ж переважну частину пацієнтів становлять особи молодого віку [3]. Крім того, больові відчуття різної інтенсивності, які є основним клінічним проявом цього патологічного стану, значно позначаються на якості життя та працездатності пацієнтів [4].

Пошук методів лікування, які б забезпечили надійне усунення ГЗ, триває вже не один десяток років. Широкий спектр традиційних і нових методів та засобів лікування цього захворювання базується на вивченні порушень загальних обмінних процесів та структурних змін у тканинах зуба й пародонту [5,6]. Проте й досі вибір оптимального методу терапії у кожному клінічному випадку може викликати певні труднощі навіть у досвідчених лікарів-стоматологів. Це у свою чергу призводить до того, що ефективність його лікування не завжди є достатньою та пролонгованою. Крім того, особливу складність викликають випадки ГЗ, які виникають на фоні рецесії ясен [7].

Тому при складанні плану лікування пацієнтів із підвищеною чутливістю зубів надзвичайно важливо правильно визначити її клінічну форму, а також виявити місцеві й загальні чинники, що сприяють виникненню цього патологічного стану та ускладнюють його перебіг. Варто також пам'ятати, що місцева та загальна консервативна терапія досить часто має поєднуватись з тими чи іншими методиками пародонтальної реконструктивно-відновлювальної хірургії. Нерозуміння цього досить часто обертається відсутністю позитивного результату лікування, а це, у свою чергу, викликає у пацієнтів почуття розчарування та недовіри до лікаря.

Метою нашої **роботи** є удосконалення лікування гіперчутливості зубів завдяки комплексному підходу до її усунення.

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The reliability of Anycheck device related to healing abutment diameter

Dong-Hoon Lee†, Yo-Han Shin†, Jin-Hong Park, Ji-Suk Shim, Sang-Wan Shin, Jeong-Yol Lee*
Department of Prosthodontics, Institute for Clinical Dental Research, Korea University Medicine, Korea University, Seoul, Republic of Korea

PURPOSE. The purpose of this *in vitro* study was to examine the reliability of the Anycheck device and the effect of the healing abutment diameter on the Anycheck values (implant stability test, IST). **MATERIALS AND METHODS.** Thirty implants were placed into three artificial bone blocks with 10 Ncm, 15 Ncm, and 35 Ncm insertion torque value (ITV), respectively (n = 10). (1) The implant stability was measured with three different kinds of devices (Periotest M, Osstell ISQ Mentor, and Anycheck). (2) Five different diameters (4.0, 4.5, 4.8, 5.5, and 6.0 mm) of healing abutments of the same height were connected to the implants and the implant stability was measured four times in different directions with Anycheck. The measured mean values were statistically analyzed. **RESULTS.** The correlation coefficient between the mean implant stability quotient (ISQ) and IST value was 0.981 ($P<.01$) and the correlation coefficient between the meant periotest value (PTV) and IST value was -0.931 ($P<.01$). There were no statistically significant differences among the IST values with different healing abutment diameters. **CONCLUSION.** There was a strong correlation between the Periotest M and Anycheck values and between the ISQ and IST. The diameter of the healing abutment had no effect on the Anycheck values. ***[J Adv Prosthodont 2020;12:83-8]***

KEYWORDS: Implant stability; Periotest; Implant stability test; Insertion torque value; Implant stability quotient (ISQ)

INTRODUCTION

The stability of a dental implant is used to predict the prognosis of the implant. The stability of an implant was defined as the ability of an implant to resist vertical, horizontal, and rotational forces and was employed as an indirect index of osseointegration and successful healing.[1]

Osseointegration occurs in two stages, the primary and secondary stages.[2] In the primary stage, implant stability is mainly achieved from mechanical engagement with cortical bone. In contrast, in the secondary stage, implant stability is achieved through bone regeneration and remodeling.[3] Adequate primary stability is a prerequisite for acceptable osseointegration. It is, therefore, imperative to quantify implant stability at several time points and predict long-term prognosis based upon the obtained implant stability measurements.

There are several methods to measure primary stability and some techniques involve non-invasive quantitative analysis, such as resonance frequency analysis (RFA) and damping capacity analysis (DCA).[4-7] One of the RFA devices, the Osstell ISQ Mentor (Osstell, Göteborg, Sweden), uses a sensor (smart-peg) coupled with an implant fixture and measures resonance frequency values that are converted into an arbitrary implant stability scale values called the implant stability quotient (ISQ).[8] DCA systems are designed to measure the damping characteristics of implants based on the contact time.

One DCA system device, Periotest M (Medizintechnik Gulden, Modautal, Germany), converts the measured contact time into arbitrary implant scale values called Periotest values (PTV).[6]

Some studies have investigated the ability of these non-invasive devices to measure implant stability and confirmed their reliability.[2,9,10] However, the correlation and reliability of both methods are controversial.[11] Some studies have shown a strong correlation between ISQs and PTVs, where-

Corresponding author:
Jeong-Yol Lee
Department of Prosthodontics, Institute for Clinical Dental Research, Korea University Medicine, Korea University, 148 Gurodong-ro, Guro-gu, Seoul 08308, Republic of Korea
Tel. +82226261522: e-mail, wddc@korea.ac.kr
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†These authors contributed equally to this work.

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as others have shown no correlation.[12,13] Because of these discrepancies, standard implant stability values have not yet been established and evaluations have been made with other methods of analysis, such as radiographic and clinical examinations, and measurement of insertion torque.

A new damping capacity method device, Anycheck (Neobiotech, Seoul, Korea) was introduced in 2017. This device measures the time of contact between the impacting-rod and the healing abutment. It strikes the healing abutment six times over during three seconds and converts the time into the implant stability test (IST) values. This device strikes the healing abutment with less force compared to the Periotest M and has a function to stop automatically when the stability is low, to protect the implant. However, little is known about the reliability of this device or the factors affecting the IST values. The purpose of this *in vitro* study was to examine the reliability of the Anycheck device and the effect of the healing abutment diameter on IST values.

MATERIALS AND METHODS

An artificial bone block (Sawbones, Pacific Research Laboratories, Vashon, WA, USA) with 0.32 g/cm^3 density was used in this experiment.[14] Three artificial bone blocks of the same size (Horizontal × Vertical × Height: 80 mm × 10 mm × 20 mm) were prepared (Fig. 1).

Thirty CMI IS-II implants (Neobiotech, Seoul, Korea) with 4.0 mm diameter and 10.0 mm length were used in this experiment. CMI IS-II implants were installed into three artificial bone blocks with 10 Ncm, 15 Ncm, and 35 Ncm insertion torque values (ITV), respectively (n = 10). Different drilling processes were applied to each block. For 10 Ncm ITV, the drilling process included point lindemann drill, surgical drill (Ø2.2, 3.0, 3.5, 4.0 mm) and cortical tap drill to get even ITV value. For 15 Ncm, the drilling process included point lindemann drill, surgical drill (Ø2.2, 3.0, 3.5, 4.0 mm). For 30 Ncm ITV, the drilling process included point lindemann drill, surgical drill (Ø2.2, 3.0, 3.5 mm). The distance between the implants was 3.5 mm and the space between the edge of the block and the implant was 4.2 mm on each side.

For examining the reliability of Anycheck device, experimental groups were established according to the ITVs and the devices used to measure implant stability (Table 1). The sensor, smart-peg, was coupled to the CMI IS-II implant fixtures (n = 30, ITV: 10 Ncm, 15 Ncm, 35 Ncm). ISQ values were measured in each implant in four different directions (buccal, lingual, mesial, and distal) and the mean ISQ values were recorded by one examiner.

Healing abutments (Neobiotech, Seoul, Korea, Diameter × Cuff: 4.0 mm × 4.0 mm) were connected to the CMI IS-II implants (n = 30, ITV: 10 Ncm, 15 Ncm, 35 Ncm). Lines were drawn 1 mm under the top of the healing abutment (Fig. 2) to standardize the height of the healing abutments for measurement by Periotest M and Anycheck.

Three bone blocks were fixed parallel to the ground and the rods hit perpendicular to the long axis of the healing abutment. Periotest M and Anycheck were used to measure implant stability when the devices were parallel to the

Table 1. Experimental groups used for correlation tests of the reliability of Anycheck values

Measuring device	Insertion torque (Ncm)		
	10	15	35
IST (Anycheck value)	(n = 10)	(n = 10)	(n = 10)
ISQ (Osstell Mentor value)	(n = 10)	(n = 10)	(n = 10)
PTV (Periotest M value)	(n = 10)	(n = 10)	(n = 10)

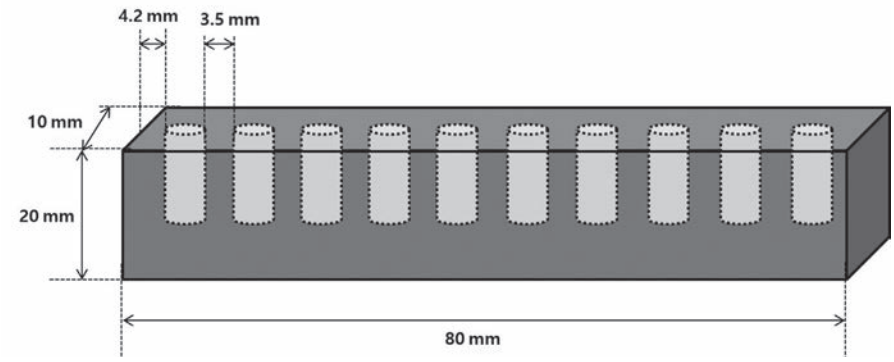

Fig. 1. A mimetic diagram of the block bone model. The size of the artificial block bone was: horizontal length, 80 mm; vertical length, 10 mm; and height; 20 mm. Ten CMI IS-II implants were installed with distances of 3.5 mm between the implants and spaces of 4.2 mm from the edge of the block.

Fig. 2. Healing abutment with the line marked on it. A line was marked on each healing abutment 1 mm from the top of the healing abutment to standardize the heights for measurement by Periotest M and Anycheck.

ground. The PTVs and IST values were measured in four different directions (buccal, lingual, mesial, and distal) (Fig. 3) and the mean values were recorded by one examiner.

For examining the effect of healing abutment diameter on IST value, experimental groups were established according to the healing abutment diameter and ITVs to determine the effect of the healing abutment diameter (Table 2).

Healing abutments (diameters: 4.0 mm, 4.5 mm, 4.8 mm, 5.5 mm, and 6.0 mm, cuff: 4.0 mm) were connected to the CMI-II implants (n = 30, ITV values: 10 Ncm, 15 Ncm, and 35 Ncm) with 10 Ncm torque using a torque ratchet. The IST values were measured in four different directions (buccal, lingual, mesial, and distal) (Fig. 3) and the mean values were recorded by one examiner.

Statistical analyses were conducted with SPSS statistics 20.0 (IBM, Chicago, IL, USA). Pearson's correlation test was conducted to analyze the correlation between ISQ and IST and between PTV and IST. One-sample Kolmogorov-Smirnov tests were conducted to test the normality of the obtained data and, based on the result of this test, two-way ANOVA tests were conducted to analyze the effect of the healing abutment diameter on the IST value. Tukey's post-hoc tests were conducted.

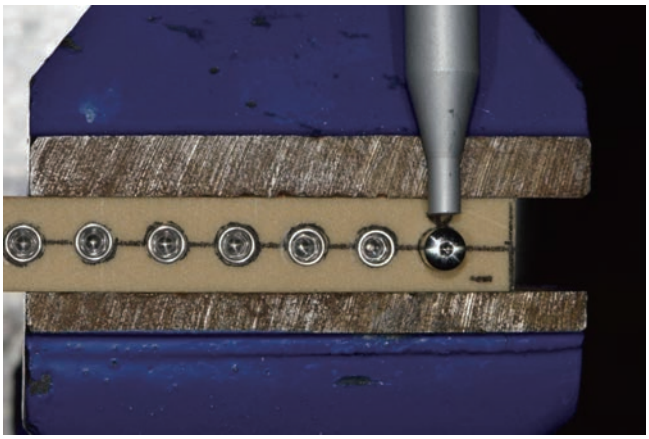

Fig. 3. Measuring the Anycheck value. Healing was connected to the implant with 10-Ncm torque and the implant stability was measured with the Anycheck device in four different directions (buccal, lingual, mesial, and distal).

Table 2. Experimental groups for correlation tests of Anycheck

Diameter (Healing abutment, mm)	Insertion torque (Ncm)		
	10	15	35
4.0	(n = 10)	(n = 10)	(n = 10)
4.5	(n = 10)	(n = 10)	(n = 10)
4.8	(n = 10)	(n = 10)	(n = 10)
5.5	(n = 10)	(n = 10)	(n = 10)
6.0	(n = 10)	(n = 10)	(n = 10)

RESULTS

The correlation coefficient between the mean ISQ value and the mean IST value was 0.981, demonstrating a strong positive correlation ($P < .01$) (Fig. 4). In addition, the correlation coefficient between the mean PTV value and the mean IST value was -0.931, demonstrating a strong negative correlation ($P < .01$) (Fig. 5).

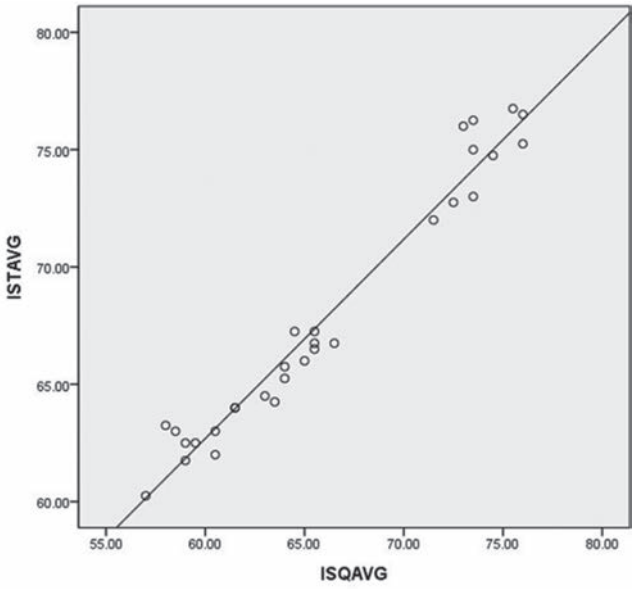

Fig. 4. The result of Pearson's correlation between the mean ISQ values (ISQAVG) and mean IST values (ISTAVG). The correlation coefficient was 0.981 ($P < .001$).

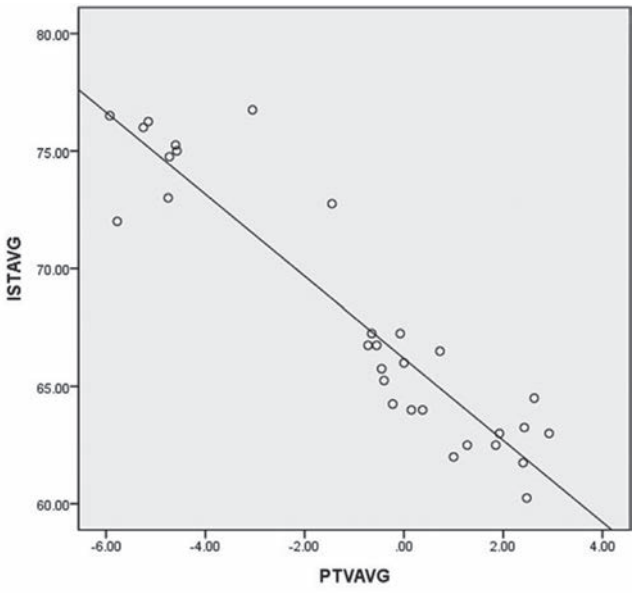

Fig. 5. The result of Pearson's correlation between mean PTV values (PTVAVG) and mean IST values (ISTAVG). The correlation coefficient was -0.931 ($P < .001$).

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The IST values were proportional to the ITV of the implants, indicating that the IST value could be an indirect index of primary implant stability based on the insertion torque (Fig. 6). When the ITV was 10 Ncm, the mean IST value according to healing abutment diameters are as follows: 62.67 ± 1.19 (4.0 mm), 62.32 ± 1.93 (4.5 mm), 62.15 ± 1.09 (4.8 mm), 61.52 ± 1.5 (5.5 mm), 61.35 ± 1.77 (6.0 mm). When ITV was 15 Ncm, the mean IST values are as follows: 65.97 ± 1.16 (4.0 mm), 65.12 ± 0.81 (4.5 mm), 64.72 ± 0.83 (4.8 mm), 65.32 ± 1.26 (5.5 mm), 64.6 ± 0.67 (6.0 mm). When ITV was 35 Ncm, the mean IST values are as follows: 74.82 ± 1.69 (4.0 mm), 73.52 ± 2.48 (4.5 mm), 73.75 ± 1.65 (4.8 mm), 74.6 ± 1.46 (5.5 mm), 74.4 ± 1.55 (6.0 mm) (Fig. 7). However, there were no statistically significant differences among the IST values with different healing abutment diameters (P = .505).

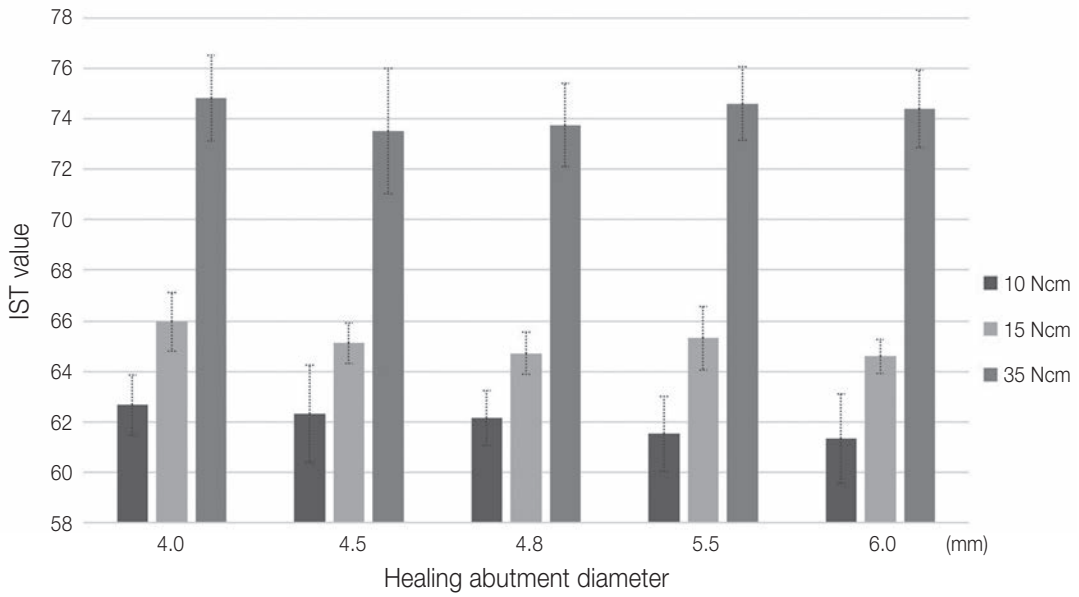

Fig. 6. The implant stability test (IST) values of implants with different insertion torque values (ITV). The IST values were significantly different among the implants installed with different ITVs with different healing abutment diameters.

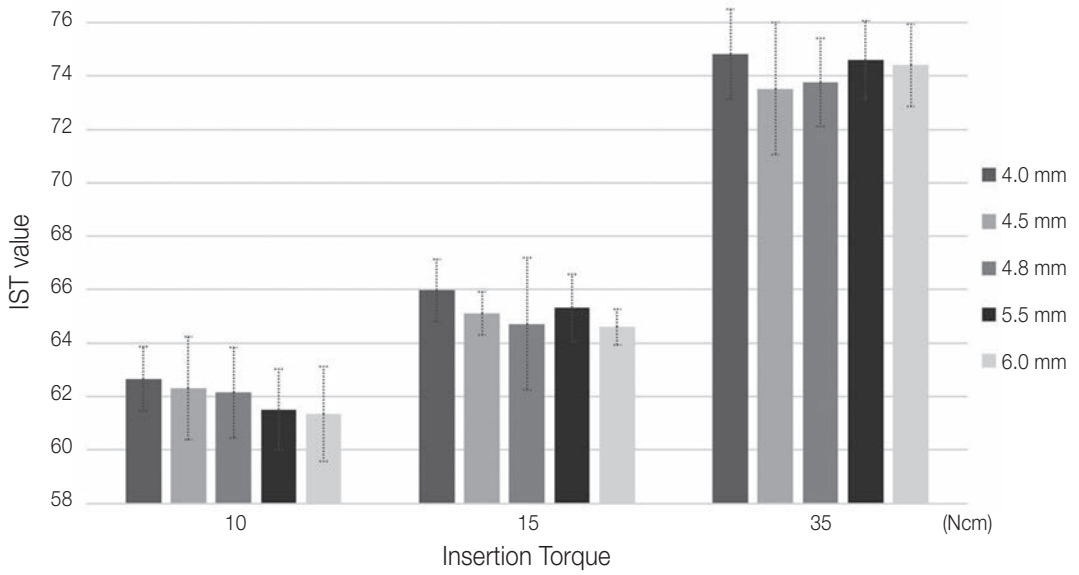

Fig. 7. Implant stability test (IST) value of implants with different healing abutment diameter. The IST value had no statistically different among healing abutment diameters with the same ITV value.

DISCUSSION

Studies have reported that both the Periotest and Osstell ISQ devices could reliably measure implant stability. Lachmann *et al.* insisted that both the Periotest and Osstell ISQ showed acceptable reliability in predicting the stability of implants in an *in vitro* experiment.[15] Pang *et al.*[11] also showed a strong association between the ISQs and PTVs after surgery and two months later. An animal study demonstrated a strong correlation between ISQs and PTVs.[12] In addition, some studies reported that although both the Periotest and Osstell ISQ systems were useful for evaluating implant stability, the Osstell ISQ system performed more accurately than the Periotest device, showing high reliability.[16,17] However, some studies have reported conflicting results for both the Periotest and the Osstell ISQ devices.[12,18] Considering this controversy, both the Periotest and the Osstell ISQ devices were tested with Anycheck device. In addition, there was no information about healing abutment dimeter. *In vitro* test for the reliability and effect of healing abutment diameter would be appropriate for setting conditions for further *in vivo* experiment. The results showed that the IST values were strongly correlated with both the PTVs and ISQs, suggesting that the IST values follow the tendency of PTV and ISQ values.

There are well known limitations and inconveniences of the Periotest and Osstell devices. Long-term data of Periotest have shown that it can be an objective measurement of implant stability.[19,20] However, some studies have pointed out that these devices lack sensitivity.[21,22] This is because Periotest, designed for natural dentition, measures a wide dynamic range (-8 to 50). However, the dynamic range used for measuring implant stability is limited to between -5 and +5.[13] Other studies have suggested that an even narrower dynamic range of -4- to -2 or -4 to +2 is needed for clinically osseointegrated implants.[23,24] Moreover, PTV cannot identify implants with borderline stability or those in the process of osseointegration.[25] PTVs have also been criticized for lack of resolution and vulnerability to operator variables.[2,26]

The Osstell ISQ is a noninvasive method that can measure implant stability and based on the principle of structural analysis.[27] This device can be fairly reliable when an implant has achieved osseointegration and the bone-implant interface is rigid. However, when the bone-implant interface is not rigid or doubtful, the ISQ tends to fluctuate.[28,29] In addition, use of the Osstell ISQ requires removal of the upper component of the fixture (cover screw or healing abutment) and connection of the smart-peg when measuring implant stability and this may cause inconvenience and limitations.

The newly developed Anycheck device values were consistent with ISQ values. In addition, the Anycheck device values ranges from 1 to 99. The tapping motion was also improved with lesser tapping times and forces applied to the implant, resulting in safer measuring of implant stability than that of the Periotest. Use of the Anycheck does not require unscrewing the healing abutment and thus the process is easier than that of Osstell ISQ.

One study used the Periotest device to measure implant stabilities, regardless of whether the patients had single crowns, abutments, or healing abutments. The results showed that the diameter of the implant supra structure did not affect the IST value. If this idea can be applied to the Anycheck device, there is a possibility of measuring implant stability not only before the delivery of the prosthesis but also after the delivery of prosthesis. However, further studies investigating the effect of the curvature of the prosthesis and prosthetic material on IST values of the final prostheses are required before the Anycheck device is used clinically.

The limitation of this *in vitro* study was that the reliability of Anycheck was based on the correlation between the other devices and the agreement rate of each device was not measured in this experiment. In addition, the study design cannot compare the devices in osseointegrated implants and further *in vivo* studies are required for the clinical usage. The correlation between the devices may reveal tendencies toward implant stability but cannot suggest exact values indicating implant prognosis. Further studies are required to determine the reliability of the Anycheck device for clinical use.

CONCLUSION

Within the limitations of this study, we can conclude that the IST values had as strong positive correlation with the ISQ values and a strong negative correlation with the PTVs. In addition, based on the results of this study, the diameter of the healing abutment had no statistically significant effect on the IST values. The Anycheck device demonstrated relative reliability based on the reliability of Osstell and Periotest M. The device can be applied to the various diameters of healing abutments because the IST values were not affected by the diameter of the healing abutments.

ORCID

Dong-Hoon Lee *https://orcid.org/0000-0002-9592-3259*
Yo-Han Shin *https://orcid.org/0000-0003-0341-1078*
Jin-Hong Park *https://orcid.org/0000-0002-3220-9912*
Ji-Suk Shim *https://orcid.org/0000-0002-4112-6051*
Sang-Wan Shin *https://orcid.org/0000-0002-3100-2020*
Jeong-Yol Lee *https://orcid.org/0000-0003-3079-0376*

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Original Article

Comparison Study of Periotest M and AnyCheck for Tooth Stability Measurement at the Incisal Edge of the Crown During Active Orthodontic Treatment: A Suggested Protocol

Eduardo Yugo Suzuki[1], **Boonsiva Suzuki**[1]

[1]Department of Orthodontics, Faculty of Dentistry, Bangkokthonburi University, Bangkok, Thailand

Abstract

Assessment of tooth stability (TS) during orthodontic treatment provides relevant information regarding the biomechanical behavior of the periodontium. Therefore, the purpose of the present study was 1) to compare the performance of the Periotest M and the AnyCheck in assessing tooth stability, 2) to compare the measurement of TS values obtained from the middle and the incisal edges, and 3) to develop a protocol of tooth stability measurement during the active phase of orthodontic treatment. Comparison of reliability of the Periotest M (Medizintechnik Gulden, Modautal, Germany) and the AnyCheck (IMT-100, DMS Co., LTD. Gangwon-do, Korea) was performed on 20 participants. Both devices are designed to provide objective measurements by assessing the damping capacity. Since the periotest values are displayed in PTV values and AnyCheck displayed in the iST scale (Implant Stability Test), a conversion equation to convert PTV into IST values was developed. A comparison of tooth stability values obtained from the middle and the incisal edge was performed to allow measurements during the active orthodontic treatment. Data was collected and analyzed statistically. Significant differences in TS measurements between the middle and incisal sites were observed. The Periotest produced the largest discrepancies (42.2%, ± 22.2%) between the middle and incisal readings. (p<0.001) Measurements of the posterior teeth were not possible with the Periotest due to the bulky head size. The AnyCheck produced reduced discrepancies between the middle and incisal readings (6.8%, SD 1.9%) with no significant changes in the posterior teeth. Relatively simple measurements were possible with AnyCheck. The correlation coefficient between the mean Periotest M and AnyCheck values was 0.870 (P<0.01). A strong correlation between the Periotest M and AnyCheck values was observed. The use of incisal edge for tooth stability measurements provided reliable and consistent tooth stability measurements. Moreover, it allows measurement during the active phase of orthodontic treatment.

Keywords: AnyCheck, Orthodontic tooth movement, Periotest M, Tooth stability

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Correspondence to:
Boonsiva Suzuki, Department of Orthodontics, Faculty of Dentistry, Bangkokthonburi University, Bangkok, Thailand
E-mail: boonsiva.suz@bkkthon.ac.th

Introduction

Assessment of tooth stability has shown to be an important clinical indicator of the health status and biomechanical behavior of the periodontium during orthodontic tooth movement.[1,2] The continuous remodeling of the periodontal tissues during orthodontic tooth movement promotes the increase in tooth mobility.[1] Therefore, the assessment of tooth mobility changes can be used as an important evaluation tool for the evaluation of the biomechanical characteristics of the periodontium.[2] Consequently, the assessment of TS values can be used as a clinical indicator of the tooth movement and treatment duration. Moreover, it is commonly accepted that tooth mobility increases during orthodontic treatment and is gradually restored to baseline levels after completion of orthodontic treatment.[3,4] Therefore, the assessment of tooth stability changes during orthodontic treatment and at the retention period has been investigated.[1-5] Tanaka *et al.* had performed the longitudinal measurements of tooth mobility during orthodontic treatment using a Periotest.[4] However, measurements were performed only on the anterior teeth.

Several studies had been performed to assess the values of tooth stability in permanent dentition using different approaches.[6-10] However, their acceptance has been limited because of the subjectivity associated with their use.[6] The Periotest is a non-invasive, electronic device that provides an objective measurement of the reaction of the periodontium to a defined impact load applied to the tooth crown. Consequently, the assessment of tooth stability with the Periotest as a special test for assessing the periodontal status of teeth in children that have suffered trauma has been broadly used.[7-10]

This method has been described as an efficient and reliable method to assess tooth mobility.[11] The Periotest measures the mobility and damping of natural teeth by measuring the acceleration in response to an applied impact.[2-4] The periotest values are displayed in PTV values (-8 to +50), with a higher scale representing lower stability or higher mobility. The Periotest values are related to clinical tooth mobility through a simple correlation.[6]

Recently, a new measuring device, AnyCheck (IMT-100, DMS Co., LTD. Gangwon-do, Korea) has been introduced to assess the stability of dental implants.[12,13] This device uses the tapping method which measures the time the tapping rod of the device contacts the implant fixture. The result of measurement is displayed in the iST (Implant Stability Test) scale (1 to 99) with a higher scale representing greater stability or lower mobility.

Both the Periotest M and the AnyCheck devices are dynamic devices designed to provide objective measurement of tooth mobility and implant stability by assessing their damping characteristics. However, the AnyCheck device has not been tested for the measurement of tooth stability. Moreover, according to the manufacturer's instructions, the handpiece must be oriented perpendicular to the tooth's long axis with the tapping rod being placed towards the middle of the anatomical crown.[6-11] However, the middle of the anatomical crown is often the selected place for the orthodontic buccal brackets placement. Consequently, monitoring tooth stability with such devices during the active phase of orthodontic treatment is not possible.

To avoid these limitations, the authors propose an alternative measurement method by modifying the point of impact of the tapping rod to the incisal edge of the anatomical crown, consequently allowing the measurement of tooth mobility throughout the orthodontic treatment. However, the impact of these changes on the reliability of the measurements has not been investigated.

Therefore, the purpose of the present study was 1) to compare the performance of the Periotest M and the AnyCheck in assessing tooth stability, 2) to compare the measurement of TS values obtained from the middle and the incisal edge, and 3) to develop a protocol of tooth stability measurement during the active phase of orthodontic treatment.

Materials and Methods

Assessment of Tooth Mobility

Periotest M vs AnyCheck

In the first part of the study, the selection of the best equipment for tooth stability measurement was made. Therefore, the comparison of Periotest M (Medizintechnik Gulden, Modautal, Germany) and the AnyCheck (IMT-100, DMS Co., LTD. Gangwon-do, Korea) in assessing tooth stability was performed on 560 teeth of 20 volunteer participants. (Fig. 1 A-C) Measurements were performed of all maxillary and mandibular teeth.

Tooth stability assessment was performed following the instructions of the manufacturer. Measurements were performed with the participants seated in the dental chair in an upright position with a stable headrest. The tapping rod of the measurement device was placed in the middle of the anatomical crown. For the Periotest M device, the tapping rod was placed in a horizontal position 0.5–2 mm away from the tooth surface. Measurements are performed with the handpiece positioned perpendicular to the long axis of the tooth. (Fig. 1D-G) Measurements were performed by two trained examiners. Each measurement was performed twice for each tooth and was averaged for analysis.

Conversion Formulas

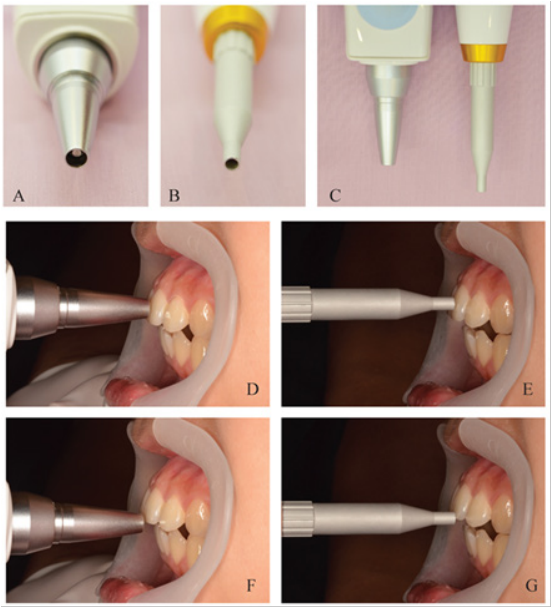

Figure 1 *Close-up pictures of the tips of the AnyCheck and Periotest M devices. Measurement devices were placed in the middle and the incisal edge of the tooth crown*

Both the Periotest M and the AnyCheck are dynamic devices designed to provide objective measurement of tooth stability by assessing damping characteristics of the periodontium. The periotest values are displayed in PTV values (-8 to +50), with a higher scale representing lower stability or higher mobility. In contrast, the AnyCheck values are displayed in iST (implant stability test) values (1 to 99) with a higher scale representing higher stability or lower mobility. Therefore, to allow the comparison of the standard deviations of the two devices, a conversion formula was created for both converting the PTV values into iST values. Moreover, since the Periotest M was designed to provide tooth stability values and the AnyCheck was designed to provide stability values, the conversion formula was proposed to represent the stability values.

The conversion of the PTV values into the iST values to assess stability was performed using the following equation: iST = 99 – ((PTV+8) * 99/58)

In this formula, the PTV values, which range from -8 to +50, thus containing a 58-unit scale, were converted into a 99-unit scale. The 0 to 99 scale is used for the iST assessment.

In this formula, the higher PTV scales represent the lower stability or higher mobility, while the higher iST scales represent higher stability and lower mobility.

Alternative Target Point for Tapping. (Middle versus Incisal edge)

In the second part of the study, the selection of an alternative target point for the tapping rod was performed to allow consistent and repeatable measurements during the active phase of orthodontic treatment.

For the conventional measurement for TM, the tapping rod of the measurement device is positioned at the middle of the anatomical crown perpendicular to the tooth's long axis. (Fig 2.) However, this position interferes with measurements during the active phase of orthodontic movement since this position coincides with the site where the orthodontic bracket is placed. Therefore, an alternative target point for the tapping rod was performed to allow

consistent and repeatable measurements during the active phase of orthodontic treatment.

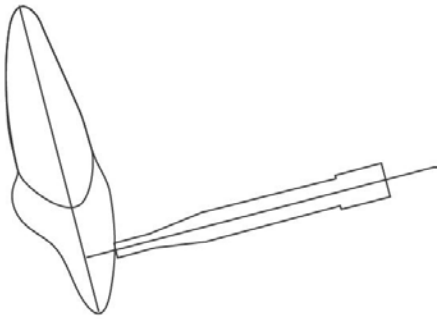

Figure 2 *Illustration of the tapping position perpendicular to the tooth's long axis*

All measurements were performed using the Periotest M and the AnyCheck device. The periotest values were converted into iST values using the proposed formula to allow comparison between devices.

Therefore, the selected point for the anterior incisors, canines, and premolars was the incisal edge perpendicular to the long tooth axis. For the molars, the selected point was the incisal edge of the mesial cusp. (Fig. 3)

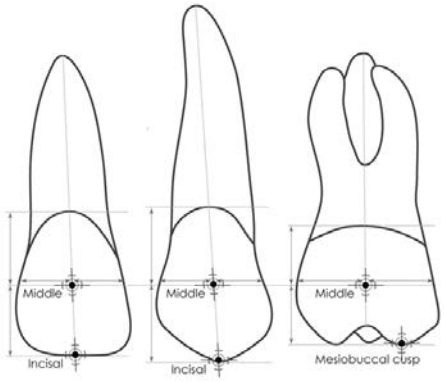

Figure 3 *Illustration of the middle and the incisal edge target sites for tapping*

The selected target point provides a reliable reference for tooth stability measurements during all phases of Orthodontic treatment, including at the baseline active and retention periods. (Fig. 4)

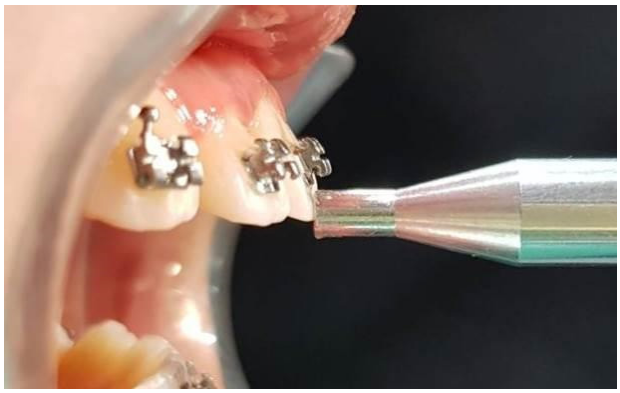

Figure 4 *Assessment of tooth stability during active orthodontic treatment*

Measurements performed at the middle and the incisal edge of the dental crown were performed to detect the differences between the different sites.

Participants

Assessment of tooth stability was performed on 560 teeth from 20 pre-orthodontic patients at the Graduate Clinic, Department of Orthodontics, Faculty of Dentistry, Bangkokthonbuti University between Jan 2018 – Jun 2018. This study was approved by the Human Experimentation Committee, Faculty of Dentistry, Bangkokthonburi University (Approval Number: 26/2561). Informed consent was obtained from all participants before the initiation of the study.

Inclusion and exclusion criteria

The overall inclusion criteria were; participants with good general health, excellent oral hygiene with sound teeth with normal shape and size, no periodontal disease nor bone loss visible on panoramic radiographs. Also, they should have no history of dental trauma nor previous orthodontic treatment with an absence of large restorative treatment such as large filling or crowns as well as no missing teeth except for the third molars.

Inter and intraindividual calibration

For the reproducibility and reliability of the measurements, inter-and intraindividual reliabilities were

performed using the intraclass correlation coefficients (ICC). Tooth stability was conducted twice at the incisal edge and the middle of the dental crown. For the middle of the dental crown measurements, the ICC was 0.850 and 0.915 for the inter-and intraindividual reliabilities, respectively. Whereas for the incisal edge of the dental crown measurements, the ICC was 0.801 and 0.844 for the inter-and intraindividual reliabilities, respectively.

Statistical Analysis

SPSS version 27.0 (IBM Corp., Armonk, NY, USA) was used for statistical analysis of the results. The paired *t*-test was used to compare the Periotest M and AnyCheck measurements at the middle and incisal edges. The agreement between the Periotest M and AnyCheck values measurements was evaluated with Pearson's correlation and coefficient and Bland-Altman analysis. The level of significance was set at 95% ($P<0.05$).

Results

Periotest M vs AnyCheck

Results of tooth stability measurements using the Periotest M (PTV values were converted in iST*) and AnyCheck values (iST) are shown in Table 1. There were no observed significant differences in the tooth stability values between both measurements. However, the Periotest M device could not perform measurements in the posterior molar area due to the large head. The Anychek device, presenting a longer and thinner tip for measurement, allowed simple measurement in both the anterior and the posterior teeth. The correlation coefficient between the mean Periotest M and AnyCheck values was 0.870 ($P<0.01$). Figure 5 Bland-Altman analysis demonstrated good agreement between the Periotest M and AnyCheck measurements. The results indicate that there is no consistent bias of one approach versus the other. (Fig. 6)

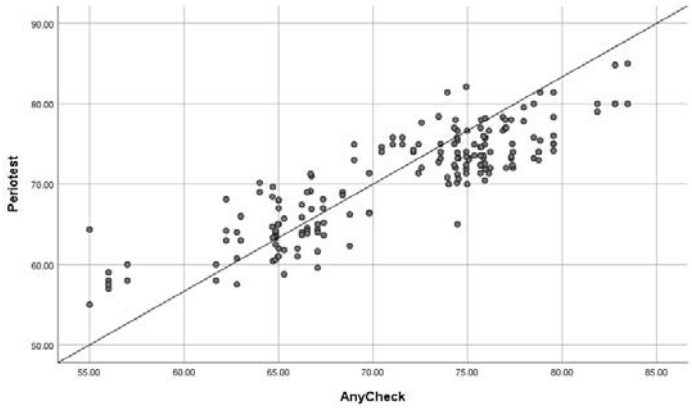

Figure 5 *Correlation of the Periotest M and AnyCheck values*

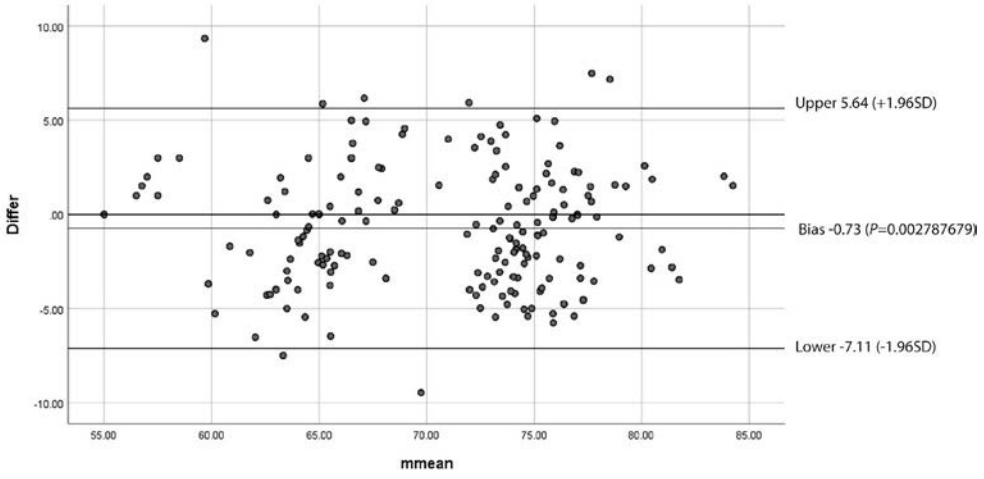

Figure 6 *Bland-Altman analysis to compare the reliability of the two measurements*

Table 1 *Assessment of tooth stability at the incisal edge using Periotest M and AnyCheck*

		Periotest M (PTV)				AnyCheck (iST)		*P* value
		PTV		iST*		iST		
		Mean	SD	Mean	SD	Mean	SD	
Maxilla	Central Incisor	14.2	2.3	61.1	5.9	66.2	4.7	0.335
	Lateral Incisor	12.5	2.2	64.0	4.7	64.7	4.3	0.464
	Canines	4.8	2.3	77.1	4.9	73.5	4.2	0.715
	First Premolar	9.5	2.2	69.1	4.0	72.6	4.0	0.468
	Second Premolar	5.7	3.7	75.6	5.9	71.5	4.2	0.406
	First Molar	4.1	5.3	78.3	5.1	76.2	3.9	0.626
	Second Molar	n/a				73.9	4.7	n/a
Mandible	Central Incisor	15.0	2.5	59.7	4.3	62.0	3.7	0.457
	Lateral Incisor	13.8	2.7	61.8	5.8	64.4	4.3	0.476
	Canines	7.7	3.0	72.1	5.1	73.1	5.0	0.696
	First Premolar	7.8	2.6	72.0	4.6	74.9	4.4	0.732
	Second Premolar	8.0	4.1	71.6	5.3	74.4	4.9	0.484
	First Molar	2.3	6.7	81.4	9.9	80.1	3.5	0.665
	Second Molar	n/a				76.2	3.9	n/a

PTV values were converted into iST values using the conversion equation*

Paired t-test, significant at P<0.05. n/a = Not applicable

Alternative Tapping Point (Middle versus Incisal)

Comparisons of tooth stability measurements between the middle and the incisal edge of the tooth's crown with Periotest M and AnyCheck are presented in Tables 2 and 3. Significant differences in tooth stability between both sites were observed.

For the Periotest M, a significant increase in the overall incisal readings (42.2%, SD 22.2%) was observed (p<0.001). The largest differences were observed in the anterior teeth. In Table 2, a moderate correlation (0.421) between the middle and incisal edge measurements was observed. (P<0.01) (Table 4)

For the AnyCheck, although an overall decrease in all incisal readings (6.8%, SD 1.9%) was observed, no significant changes in the tooth stability readings in the posterior teeth were observed. Table 3 A strong correlation (0.868) between the middle and incisal edge measurements was observed. (P<0.001) (Table 4)

Table 2 *Comparison of tooth stability values between middle and incisal sites using Periotest M*

		Periotest M (PTV)							
		Middle		Incisal		Diff		(%)	*P* value
		Mean	SD	Mean	SD	Mean	SD		
Maxilla	U1	7.37	2.73	14.2	2.3	6.8	-0.5	93.0 %	<0.001***
	U2	9.15	3.19	12.5	2.2	3.3	-1.0	36.4 %	<0.001***
	U3	4.01	2.50	4.8	2.3	0.8	-0.2	20.0 %	0.002**
	U4	5.72	1.79	9.5	2.2	3.8	0.4	66.7 %	<0.001***
	U5	4.41	1.00	5.7	3.7	1.3	2.7	29.5 %	0.002**
	U6	3.67	1.39	4.1	5.3	0.4	3.9	12.0 %	0.004**
	U7	n/a		n/a					

Table 2 *Comparison of tooth stability values between middle and incisal sites using Periotest M (cont.)*

		Periotest M (PTV)							
		Middle		Incisal		Diff		(%)	*P* value
		Mean	SD	Mean	SD	Mean	SD		
Mandible	L1	11.05	1.07	15.0	2.5	4.0	1.4	36.2 %	<0.001***
	L2	10.87	1.94	13.8	2.7	2.9	0.7	26.9 %	0.005**
	L3	5.91	1.32	7.7	3.0	1.8	1.7	31.0 %	0.006**
	L4	5.64	1.91	7.8	2.6	2.2	0.6	38.7 %	0.008**
	L5	5.43	2.34	8.0	4.1	2.6	1.7	48.3 %	<0.001***
	L6	1.47	0.91	2.3	6.7	0.8	5.8	56.1 %	0.004**
	L7	n/a		n/a					
	Mean	6.2	1.8	8.8	3.3	2.6	1.4	41.2 %	<0.001***

*Paired t-test, * P< 0.05, **P < 0.01, ***P < 0.001. n/a = not applicable*

Table 3 *Comparison of tooth stability values between middle and incisal sites using AnyCheck*

		AnyCheck (iST)							
		Middle		Incisal		Diff		(%)	*P* value
		Mean	SD	Mean	SD	Mean	SD		
Maxilla	U1	71.7	4.3	66.2	4.7	5.4	-0.4	7.6 %	0.042*
	U2	71.5	5.7	64.7	4.3	6.8	1.3	9.5 %	0.048*
	U3	78.4	5.5	73.5	4.2	4.9	1.3	6.2 %	0.025*
	U4	78.4	4.2	72.6	4.0	5.9	0.2	7.5 %	0.036*
	U5	76.2	4.2	71.5	4.2	4.6	0.0	6.1 %	0.124
	U6	81.4	4.4	76.2	3.9	5.2	0.6	6.4 %	0.126
	U7	77.1	5.5	73.9	4.7	3.2	0.8	4.2 %	0.133
Mandible	L1	68.6	6.1	62.0	3.7	6.6	2.4	9.6 %	0.048*
	L2	70.5	4.6	64.4	4.3	6.1	0.3	8.7 %	0.040*
	L3	79.8	3.7	73.1	5.0	6.6	-1.3	8.3 %	0.137
	L4	78.9	3.1	74.9	4.4	4.0	-1.3	5.1 %	0.234
	L5	79.4	3.2	74.4	4.9	5.0	-1.7	6.3 %	0.244
	L6	83.1	2.0	80.1	3.5	3.0	-1.5	3.6 %	0.246
	L7	80.2	4.7	76.2	3.9	4.0	0.7	5.0 %	0.181
	Mean	76.8	4.4	71.7	4.3	5.1	0.1	6.7 %	0.056

*Paired t-test, * P< 0.05, n/a = not applicable*

Table 4 *Correlation between measurements at the incisal edge and middle of the crown using Periotest M and AnyCheck*

	Incisal and Middle	*P*-value
Periotest M	0.421	0.007**
AnyCheck	0.868	<0.001***

Pearson correlation coefficient, significant at P< 0.01 and **P < 0.001*

Discussion

The orthodontic force applied to teeth generates specific compressive and tensile mechanical loading patterns that create complex biological responses in the periodontal tissues surrounding the loaded teeth.[14] As a result, the remodeling of the alveolar bone occurs accompanied by the widening of the periodontal ligament to allow the dental movement towards the compressive direction.[15,16] These sequential events play an important role in tooth stability. Therefore, the accurate determination of the tooth stability values at the baseline, and the changes during the active and retentive phases of orthodontic treatment provides relevant information regarding the biomechanical behavior of the periodontium.[1-6]

However, limited information is available regarding the tooth mobility at the baseline and the changes during the active orthodontic treatment. Since most of the measurement devices use the middle of the clinical anatomical crown, monitoring tooth stability with such devices during the active phase of orthodontic treatment with conventional buccal appliances is not possible.

In the present study, the authors describe a protocol for the measurement of tooth mobility and stability that can be applied during the active phase of the orthodontic treatment.

The Periotest M method has been described as an efficient and reliable method to assess tooth mobility.[11] Consequently, most studies involving assessment of tooth mobility utilize the Periotest M device to obtain reliable data. Recently, a new stability-measuring device, AnyCheck, has been introduced in the field of dental implantology. [12,13] Similar to the Periotest M device, the AnyCheck device measures fixture stability by using damping capacity analysis. Comparison of the sensitivity and reliability of the Periotest M and the AnyCheck for the assessment of the stability of dental implants have demonstrated a strong correlation between measurements.[12,13] Lee *et al.,* observed a strong correlation between Periotest M and AnyCheck values in an *in vitro* study.[12] Later, Lee *et al.* observed similar results in an *ex vivo* experiment.[13]

In the present study, the comparison of the sensitivity and reliability of the Periotest M and the AnyCheck for clinical assessment of tooth stability have demonstrated a strong correlation between measurements.

To the author's knowledge, the clinical use of the AnyCheck for assessing tooth stability values has not been performed. Moreover, to allow the comparison of tooth stability values obtained by both devices, a conversion formula was elaborated to convert PTV values into iST values.

In the present study, Bland-Altman analysis was performed to compare the reliability of the two measurements. No significant difference was found between the Periotest M and AnyCheck readings in the incisal sites. Moreover, a significantly strong correlation between both measurements was observed. The results are in agreement with previous studies that compared the Periotest M and AnyCheck values of implant stability.[12,13]

However, the Periotest M could not perform adequate and reliable measurements on posterior teeth. Repetition of several measurements was needed to obtain final tooth stability readings. This difficulty became more evident in the measurement of the posterior teeth. This difficulty was also reported by previous studies due to the difficulty of positioning the device as per the manufacturer's manual.[11]

Moreover, the Periotest M was hard to handle and measurements were time-consuming with several tooth measurements readings and the assessment of the second molars was not possible. The main reason for this difficulty was the large number of tapping times required for measurements, and relatively heavy tapping forces applied to the tooth. Moreover, the bulky size of Periotest M tips (large and short) and the need to maintain a constant clearance distance (0.5 to 2.0 mm) from the tooth surface to allow measurements, including difficult measurements with the Periotest M.

In contrast, the AnyCheck device was relatively simple and easy to handle. It allowed for relatively more simple and easy measurements of tooth stability in both

the anterior and posterior sites. Therefore, compared to the Periotest M, the AnyCheck device is more "user-friendly".

Comparison of different sites of tooth stability between the middle and incisal edge of the tooth's crown showed contrasting results between the Periotest M and the AnyCheck results.

For the Periotest M, a large discrepancy between the middle and incisal edge measurements was observed. The incisal edge site produced the largest tooth mobility values compared to the middle sites. The higher differences were observed more in the anterior teeth, in particular to the maxillary incisors. However, only a moderate correlation between reading between the middle and the incisal edge measurements was observed. Such discrepancies might be explained by the differences in the distances from the tooth's center of resistance, which is located in the middle third of the roots.

For the AnyCheck device, the significant differences between the middle and incisal edge readings were observed only with the anterior teeth. Moreover, the differences between the middle and incisal edge readings were eight times smaller than the differences observed with the Periotest M readings. In the posterior area, no significant differences in the middle and incisal edge readings were observed. This might be explained by the relatively short clinical crown observed in the posterior teeth and the relatively small distances between the middle and incisal edges observed in the posterior teeth.

Therefore, based on the results of this study, the AnyCheck device might be considered as an alternative equipment for evaluating the damping capacity of tooth stability.

A limitation of the present study might be the presence of inter-individual variation, such as the skeletal pattern, gender, and age. Therefore, further studies are necessary to assess factors related to the differences in tooth mobility.

In the present study, the authors had proposed an alternative measurement protocol for tooth stability by using the AnyCheck device and by modifying the point of impact of the tapping rod to the incisal edge of the tooth's anatomical crown. Such modifications have provided reliable and consistent tooth stability measurements. Consequently, the assessment of tooth stability throughout the active phase of the orthodontic treatment can be easily and consistently performed following this protocol.

Although it is generally known that an increase in tooth mobility occurs during orthodontic treatment, limited information regarding the amount of tooth mobility changes or the limits of safe tooth mobility values during active orthodontic treatment is available. Moreover, the possibility of using the tooth mobility analysis for predicting quantitatively the amounts of tooth movement might allow the construction of algorithms to precisely predict the overall optimum treatment duration. Therefore, further studies to assess the physiological values of the tooth mobility at the baseline, during the active and the retention phases of the orthodontic treatment, should be investigated in future studies.

Conclusions

1. A strong correlation between Periotest M and AnyCheck values in clinical measurements was observed.

2. The use of the incisal edge for tooth stability measurements provided reliable and consistent tooth stability measurements. Moreover, it allows for measurement during the active phase of orthodontic treatment.

3. The AnyCheck device allowed for relatively more simple and easy measurements of tooth stability in both anterior and posterior sites. Therefore, it might be considered as an alternative and reliable equipment for evaluating the damping capacity of tooth stability.

4. A protocol of tooth stability measurement using the incisal edge of the tooths' crown during the active orthodontic treatment with the AnyCheck device has been presented.

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Original Article

Assessment of Factors that Affect Primary Stability of Minimally Invasive Implant (MII): An *in vitro* Study

Yong Woan Kim, DDS, MSD[1], Seung-Ki Min, DDS, MSD, Ph.D[2], Je Won Wang, DDS, MSD[3], Kyung Su Shin, DDS, MSD[4*]

[1]Private Practitioner, L Dental Clinic, Yangsan, Korea
[2]Private Practitioner, L Dental Clinic, Daejeon, Korea
[3]Researcher, Academy of Minimally Invasive Implantology, Daejeon, Korea
[4]Fellow, Department of Oral and Maxillofacial Surgery, College of Dentistry, Wonkwang University, Iksan, Korea

*Corresponding author: Kyung Su Shin, Department of Oral and Maxillofacial Surgery, College of Dentistry, Wonkwang University, 895 Muwang-ro, Iksan, Korea
Tel : +82-10-2402-5756. Fax : +82-63-859-4002. E-mail : 5848463@naver.com

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ORCID
Kyung Su Shin
http://orcid.org/0000-0002-5699-3414

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YWK designed and conducted experiments. JWW and SGM reviewed the test data. KSS drafted the manuscript and critically revised the manuscript. All authors read and approved the final manuscript.

Consent for Publication
Written informed consent was obtained from the patient for the publication of this report and any accompanying images.

Conflict of Interests
The authors declare no conflict of interest.

Abstract

Purpose: This study aimed to evaluate the factors affecting the primary stability of a new implant design based on minimally invasive implantation (MAGICORE®; INNOBIOSURG Co. Ltd., Daejeon, Korea) using the evaluation index of Periotest value (PTV), implant stability quotient (ISQ), and implant stability test (IST).

Materials and Methods: A total of 1056 implants were implanted in artificial bone, imitating human bones D1, D2, D3, and D4. The PTV, ISQ, and IST values of all implants were measured according to the manufacturer's guidelines for each measuring instrument. To compare the factors affecting the stability of the implant for each measurement method, one-way ANOVA was performed, and post-hoc analysis was performed using the Games–Howel test ($p < .05$). In addition, a stepwise multiple linear regression analysis was performed to evaluate the weight of each factor.

Results: Implants with diameters greater than 5.0 mm showed significantly lower PTV values and higher ISQ and IST values. Implants with 11 mm length showed the lowest PTV and highest ISQ and IST values. A cuff size of 2 mm showed the highest implant stability among all the measurement methods. In this study, poor bone quality decreased the primary stability.

Conclusion: As the cuff size increased, the stability decreased, and the larger the diameter of the implant, the longer the length and higher the primary stability. The bone quality and diameter of the implant contributed more to the stability of the implant than to the length of the implant and cuff size.

Keywords: Implant primary stability, Implant stability quotient (ISQ), Implant stability test (IST), Minimally invasive implant (MII), Periotest value (PTV)

Ⅰ. Introduction

Dental implants have been used to restore tooth loss for the past 60 years since Professor

Brånemark discovered the osteophysiological phenomenon of titanium implants with the concept of osseointegration and have provided a stable function through bone fusion with alveolar bones.[1] The success rate of implants has been reported to be associated with good bone formation at the bone-implant contact, which provides support for transmitting loads from the implants to the bones.[2] Deposition of new bone at the bone-implant contact requires good primary stability of the implant with limited micromovements, which is associated with the mechanical union of the implant.[3]

Various studies have been conducted to improve the mechanical stability of implants, innovative surface treatment methods have been developed to allow implants to form a better bone-implant contact than before. This development has led to the concept of "early loading" or "immediate loading" of implants.[4-5] Therefore, a quantitative evaluation of the degree of osseointegration of the implant and methods for evaluating the implant stability are required. To evaluate the stability and osseointegration of implants, biopsy and reverse torque tests were initially proposed; however, they were invasive, making them difficult to apply in clinical practice or breaking the already formed bone adhesion. Therefore, various noninvasive tests have been proposed that are simple and clinically safe to apply.[6-9] Currently, two common test tools used in clinical practice are resonance frequency analysis (RFA) using the resonant frequencies of electromagnetic pulses and damping capacity analysis (DCA) using the mobility and damping characteristics of teeth and implants.[10]

As the surgical techniques for implants have continued to change, interest in minimally invasive implant surgery that minimizes the invasive nature of traditional implant surgery, such as immediate implant surgery or flapless implant surgery, has increased in recent years.[11-12] MAGICORE® IBS IMPLANT (INNOBIOSURG Co. Ltd., Daejeon, Korea) is an implant system that was developed based on the concept of minimally invasive implants (Fig. 1). It is a one-piece implant made of a single body of implant fixtures and abutment and is designed to obtain high mechanical bonds from the intact bones between threads due to a unique type of thread called "Magic Fin Thread". In addition, by applying guide pins and trephine-type drill designs, it is designed to allow minimally invasive implant surgery by

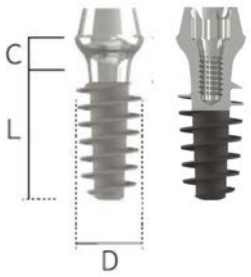

Fig. 1. MAGICORE® : Tapered one-body, tissue level implant system with a wide and deep square shape thread for minimal invasive implant surgery. Depending on the shape of the residual bone and the amount of soft tissue, a good soft tissue appearance can be obtained by using an appropriate cuff size. D, L, and C designates diameter, length, and cuff size respectively.

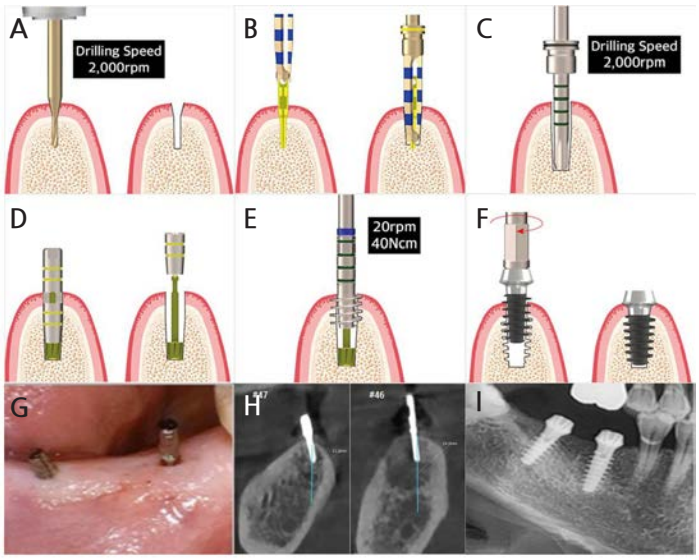

Fig. 2. Illustration of MAGICORE® implantation protocol according to the manufacturer's guideline (A-F) and clinical photos (G-I). (A) Use pin drill in the intended implant site, (B) Then insert a guide pin and obtain a cone beam computed tomography (CBCT) image to check the direction of the implant. The guide pin is also an internal guide system that helps in drilling accurately in the direction identified in the radiograph, (C) Check the depth and the diameter with the depth drill, (D) Insert the tap guide pin and check the depth & direction again, (E) Use the tap drill according to tap guide pin, (F) Place the implant with the hand torque ratchet, (G) Guide pin are inserted in the region of 46 and 47 via flapless surgery, (H) The location and direction of implant placement can be checked using CBCT and modified without making a surgical stent before surgery and modify it again in the dental unit, (I) Post-operative radiograph of minimal invasive implant placement in then 46 and 47 area.

using guided drilling without surgical stents, digital guide systems, or additional gingival flap elevation for implant drilling (Fig. 2).

The purpose of this study was to evaluate the primary stability using three different measurement methods in an artificial bone block according to the implant data and bone quality for a newly designed implant system based on a minimally invasive implant and analyze the factors affecting the primary stability of the implant.

II. Materials and Methods

1. Artificial bone block and implant data

Artificial bone blocks used a total of four blocks, one artificial dummy each imitating the human bones D1, D2, D3, and D4 (Fig. 3). A MAGICORE® IBS implant was used, with 88 types being used according to the diameter, length, and cuff size (Table 1). Three implants were used for each implant type, and a total of 1056 implants were implanted in four types of artificial bone blocks. All implants were implanted according to the manufacturer's instructions by a clinician specializing in MAGICORE®.

2. Measurement of implant stability

To evaluate the primary stability of implants, the RFA method was used to determine the implant stability quotient (ISQ) value using Ostell™ moment (Integration Diagnostic Ltd., Savedalen, Sweden). The DCA method was used to determine the Periotest value (PTV) and implant stability test (IST) using Periotest M (Medizintechnik Gulden, Modautal, Germany) and Anycheck (Neobiotech Co. Ltd., Seoul, Korea), respectively. All implants were measured by a clinician immediately after implantation according to the standard guidelines of each instrument's manufacturer by a clinician. (Fig. 4).

3. Statistical analysis

In this study, statistical analysis was performed using IBM SPSS Statistics ver. 21.0 (IBM Co.,

Fig. 3. Artificial bone block : D1 = All cortical, D2 = 3 mm cortical, D3 = 1 mm cortical, and D4 = All cancellous.

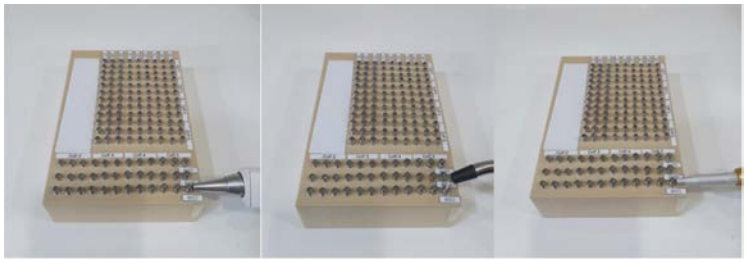

Fig. 4. The stability of the implant was measured in three different ways : (Left) Periotest M, (Middle) Osstell mentor, (Right) AnyCheck. All measuring devices are used according to the manufacturer's instructions to measure the stability of the implant.

Table 1. Summary of the included studies

Diameter	Length	Cuff	N
3.0, 3.5	11, 13	2, 3, 4, 5	16 types
4.0, 4.5, 5.5, 6.0, 6.5	7, 9, 11	2, 3, 4, 5	72 types

*unit : mm

Armonk, NY, USA). In each measurement method, one-way ANOVA was performed to analyze and compare the differences in stability according to the specifications of the implants and the bone quality of the artificial bone block, and post-hoc analysis was then performed using the Games–Howel test. ($p < .05$).

We also performed stepwise multiple linear regression analysis to evaluate the weight coefficients of the factors influencing the implant primary stability.

Ⅲ. Results

Among the 1056 implants measured by three different methods in this study, the average and standard deviation of the primary stability according to the cuff size, diameter, length of the implant, and the bone quality of the artificial bone block are shown in Table 2. The mean PTV of all MAGICORE® measured

Table 2. Mean PTV, ISQ & IST according to implant data(cuff size, diameter, length) & bone type

		PTV		ISQ		IST	
		Mean	SD	Mean	SD	Mean	SD
Cuff	2	−4.25	3.95	57.5	10.0	76.2	6.9
	3	−3.15	4.35	55.7	10.6	73.0	8.1
	4	−1.91	5.34	52.2	11.3	70.3	9.3
	5	−0.37	5.29	49.8	11.6	67.7	9.0
Diameter	3.0	0.13	3.85	41.8	7.9	72.2	2.7
	3.5	−0.3	3.53	43.2	7.2	72.7	4.0
	4.0	0.53	7.22	48.7	11.4	65.8	11.1
	4.5	−0.37	6.03	50.3	10.2	65.8	10.9
	5.0	−4.21	2.85	58.5	7.1	73.2	6.3
	5.5	−4.44	2.48	58.2	7.1	74.0	6.3
	6.0	−4.11	4.37	60.6	11.5	74.1	10.2
	6.5	−5.04	2.31	61.5	6.2	77.0	6.0
Length	7	−0.98	7.2	51.8	12.9	68.2	12.0
	9	−3.46	3.52	57.1	9.0	71.9	9.0
	11	−3.26	3.55	55.4	10.5	74.2	5.8
	13	−0.27	3.58	53.0	7.1	72.7	3.1
Bone type	D1	−5.32	2.23	60.1	8.1	76.6	5.3
	D2	−4.11	2.24	58.1	7.6	74.7	4.6
	D3	−2.75	2.86	53.3	9.1	72.2	5.5
	D4	2.32	6.88	43.7	12.1	63.7	12.1
Total		−2.42	4.98	53.8	11.3	71.8	8.9

in this study was −2.42 ± 4.98, the mean ISQ was 53.8 ± 11.3, and the mean IST was 71.8 ± 8.9.

The PTV value showed a statistically significant difference according to the cuff size ($p < .05$) (Fig. 5). Implants with a cuff size of 2 mm showed the lowest PTV value of −4.82 ± 3.84 on average. At the longest cuff size of 5 mm, the average PTV was 1.7 ± 3.28, showing the highest value, which is the statistically highest value ($p < .05$). In comparison between implant diameters, the 4.0 mm diameter implant showed the highest PTV value at 0.53 ± 7.22 but showed no statistically significant difference from the 3.0 mm, 3.5 mm, and 4.5 mm diameter implants ($p > .05$). The 6.5 mm diameter implant had the lowest PTV value of −5.04 ± 2.31, but there was no statistically significant difference from the 5.0−6.0 mm diameter implants ($p > .05$). Overall, implants with a diameter of 5.0 mm or greater showed statistically significantly lower PTV values than implants with a diameter of 3.0−4.5 mm. At PTV values according to the implant length, 9 mm long implants (−3.46 ± 3.52) and 11 mm long implants (−3.26 ± 3.55) showed statistically low PTVs compared to 7 mm long implants (−0.98 ± 7.2) and 13 mm long implants (−0.27 ± 3.58) ($p < .05$). Finally, the PTV value according to the bone quality of the artificial bone block was D1 to D4, and as the bone quality softened, a statistically significantly higher PTV value was measured ($p < .05$). Similar values were obtained when D1, the highest PTV (−5.32 ±

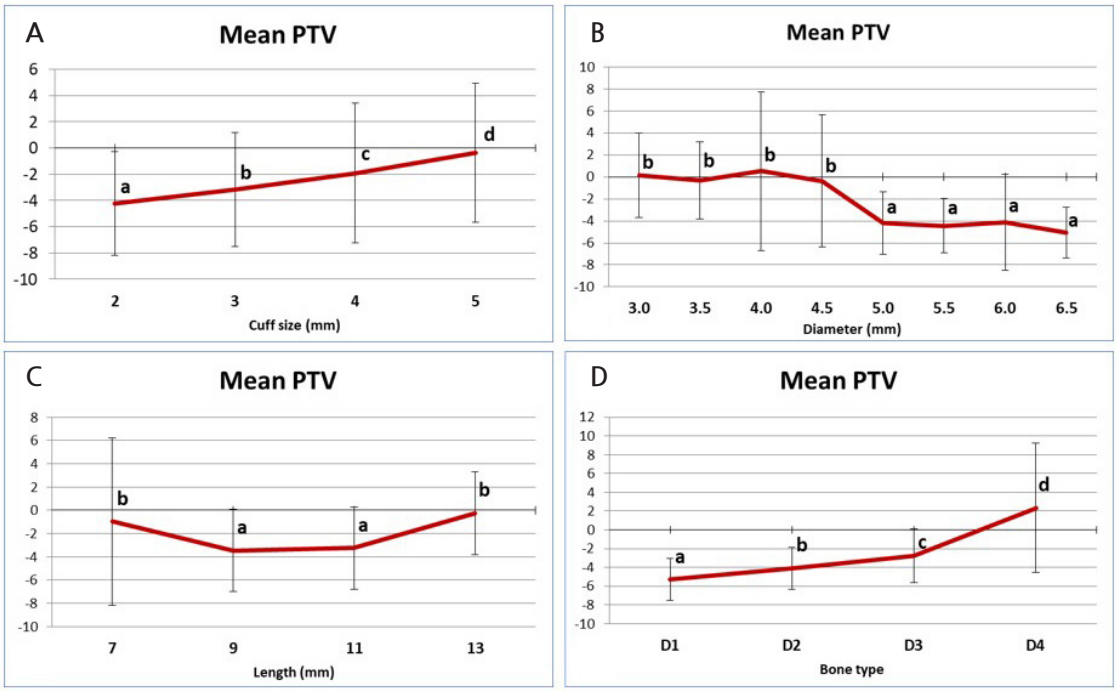

Fig. 5. A graph showing PTV according to the specifications of an implant (length, diameter, and cuff size) and bone type. Different lowercase letters denote significant differences among the groups by one-way ANOVA test and Games-Howel post-hoc test at α=.05.

2.23) was used, and when D4, the lowest PTV (2.32 ± 6.88) was used.

Similar to PTV, the ISQ value showed a significant difference according to the cuff size ($p < .05$) (Fig. 6). The cuff size showed the highest ISQ value (59.8 ± 3.8) at 1 mm and decreased significantly with increasing length, showing the lowest ISQ value at 37.4 ± 3.3 at 5 mm cuff size ($p < .05$). In comparison, according to the diameter of the implant, 3.0 mm (41.8 ± 7.9) and 3.5 mm (43.2 ± 7.2) diameter implants (41.8 ± 7.9) showed statistically significant lower ISQ values ($p < .05$). The 4.0 mm diameter implants (48.7 ± 11.4) and 4.5 mm diameter implants (50.3 ± 10.2) showed significantly higher ISQ values than those with lower diameter but had significantly lower ISQs than those with larger diameter (5.0−6.5 mm) ($p < .05$). Implants with6.5 mm diameter (61.5 ± 6.2) showed statistically significant higher ISQ values than the 5.0 mm (58.5 ± 7.1) and 5.5 mm diameter implants ($p < .05$). However, the 6.5 mm diameter implants showed no significant difference from the 6.0 mm diameter implants (60.6 ± 11.5 mm). Similar to the PTV measurements, the ISQ measurements also showed a significantly higher ISQ value as the bone quality of the artificial bone block became harder ($p < .05$). The mean ISQ was highest in D1 at 60.1 ± 8.1 and lowest in D4 at 43.7 ± 12.1 ($p < .05$).

Unlike other measurement methods, the average IST showed the lowest value (68.3 ± 9.1) for the 4

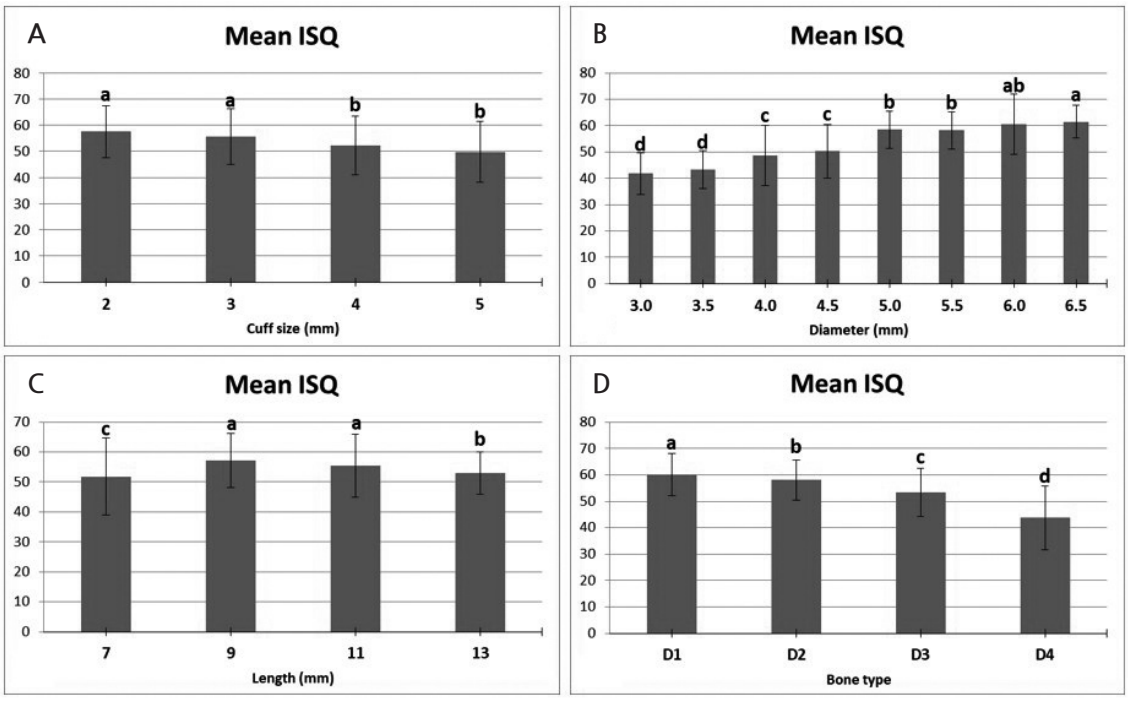

Fig. 6. A graph showing ISQ according to the specifications of an implant (length, diameter, and cuff size) and bone type. Different lowercase letters denote significant differences among the groups by one-way ANOVA test and Games-Howel post-hoc test at α=.05.

mm cuff (Fig. 7). However, there was no statistically significant difference from the 5 mm cuff implant (68.5 ± 3). Similar to the previous two measurement methods, the highest average IST value (76.4 ± 7.5) appeared at a cuff size of 2 mm ($p < .05$). IST, according to the implant diameter, showed statistically significantly lower mean IST for 4.0 mm (65.8 ± 11.1) and 4.5 mm diameter implants (65.8 ± 10.9) ($p < .05$). The 6.5 mm diameter implant (77 ± 6 mm) showed the highest IST value; however, there was no significant difference from the 6.0 mm diameter implant (74.1 ± 10.2 mm). The average IST value showed a significant difference according to the implant length ($p < .05$). The 11 mm long implant (74.2 ± 5.8) showed the highest average IST, followed by the 9 mm long implant (71.9 ± 9) and the 13 mm long implant (72.7 ± 3.1). The lowest average IST value was for the 7 mm long implant (68.2 ± 12). The difference in the IST values according to the bone quality of the artificial bone block was similar to that of the previous two methods. In D1, the mean IST was 76.6 ± 5.3, indicating the maximum value, and in D4, the mean IST was 63.7 ± 12.1, indicating the minimum value.

Table 3 displays the results of the stepwise multiple linear regression analysis for primary implant stability in this study. In the DCA method (PTV and IST), the bone type had the greatest influence on implant stability, followed by the implant diameter. In contrast, in the RFA method (ISQ), the diameter of the implant had the greatest effect on stability, followed by the bone type.

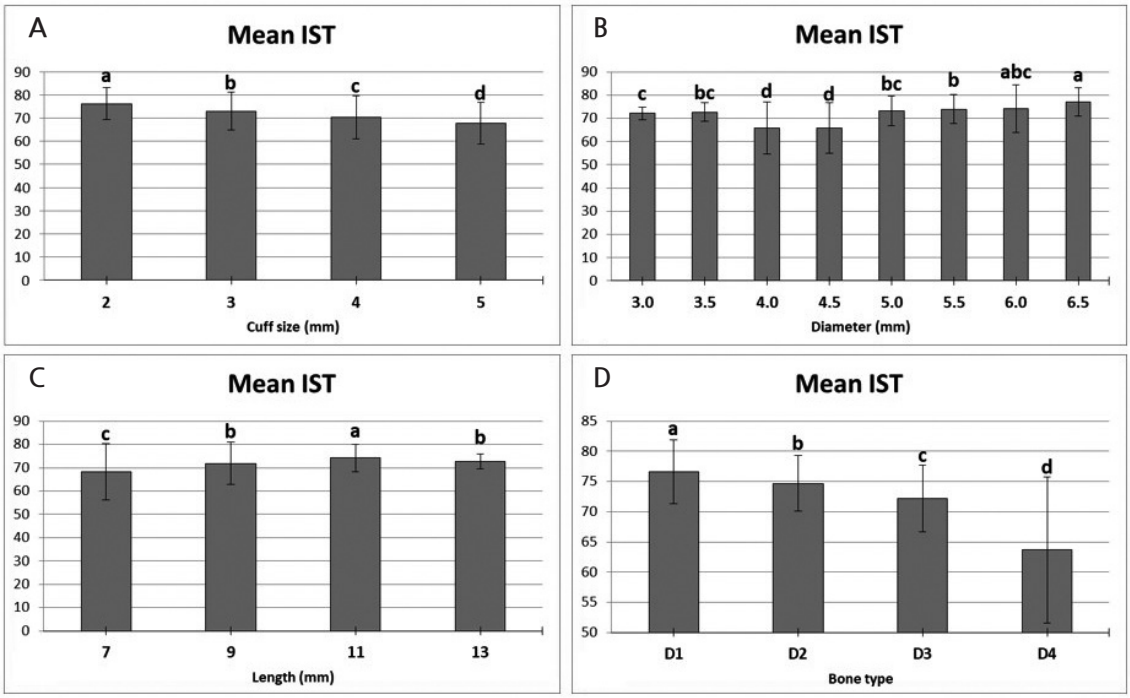

Fig. 7. A graph showing IST according to the specifications of an implant (length, diameter, and cuff size) and bone type. Different lowercase letters denote significant differences among the groups by one-way ANOVA test and Games-Howel post-hoc test at α=.05.

Table 3. Stepwise multiple linear regression analysis to evaluate implant primary stability according to implant data(cuff size, diameter, length) & bone type

Stability test	Variable	Unstand coef.		Stand coef.	t	95% confidence interval for β	
		B	SE	β		Lower	Upper
PTV	Constant	5.617	0.917		6.127	3.818	7.417
	Cuff	1.287	0.085	0.289	15.110	1.120	1.454
	Diameter	−2.374	0.096	−0.524	−24.782	−2.562	−2.186
	length	−0.739	0.055	−0.286	−13.528	−0.846	−0.632
	Bone type	2.445	0.085	0.549	28.703	2.278	2.612
ISQ	Constant	30.190	1.707		17.689	26.841	33.539
	Cuff	−2.660	0.159	−0.263	−16.776	−2.971	−2.349
	Diameter	7.037	0.178	0.683	39.458	6.687	7.387
	length	1.251	0.102	0.213	12.310	1.052	1.451
	Bone type	−5.369	0.159	−0.531	−33.863	−5.680	−5.058
IST	Constant	55.939	1.675		33.398	52.653	59.226
	Cuff	−2.831	0.156	−0.354	−18.193	−3.136	−2.525
	Diameter	3.579	0.175	0.440	20.450	3.236	3.923
	length	1.939	0.100	0.418	19.436	1.743	2.135
	Bone type	−4.098	0.156	−0.513	−26.339	−4.403	−3.793

*$p < .001$ in all variable
R square: PTV = 0.613, ISQ = 0.740, IST = 0.600
Abbreviations: Unstand coef = unstandardized coefficients, Stand coef = standardized coefficients, SE = standard error.

Ⅳ. Discussion

Implant stability can be divided into primary and secondary stability. Primary stability is caused by the mechanical bonding of the implant inserted into the bone.[3] Secondary stability is the biological stability that occurs through bone regeneration and remodeling.[13] The relative displacement of 50−150 μm or more between the bone and implant contact can result in fibroblastic bone formation, which can greatly reduce the long-term secondary stability.[14-15]

The RFA and DCA methods are widely used to quantitatively evaluate the stability of implants.[10] The RFA measurement method numerically represents the stability of an implant using electromagnetic resonance frequency (ISQ). After connecting a magnetic "smartpeg" to the implant, the probe vibrates at a certain frequency to display the returning frequency value numerically.[7] This value is higher when the binding contact between the bone and the implant is stronger, and the range is between 1 and 100. Nedir et al.[16] proposed an ISQ value of 49 or higher for traditional delayed loading and 54 or higher for

immediate loading.

The DCA method includes Periotest, which was used traditionally, and AnyCheck, which has recently been developed and released. Periotest is determined by measuring the time at which the metal rod touches the surface of the healing abutment or implant prosthesis and then returns, converting it into a PTV between −8 and +50.[8] Periotest has a cutoff of −2 and provides reliable predictability.[17] AnyCheck was launched in 2017 as an implant stability measurement device using the DCA method. It examines the implant prostheses or abutments six times in three seconds, measures the contact time, and displays them as IST values. The IST is expressed as a range between 1 and 99; a higher number was associated with a shorter contact time and higher implant stability level.[18] Extensive research data on measurements and stability are lacking; however, clinically, an IST of 1−59 indicates low stability, 60−64 indicates moderate stability, and >65 indicates high stability. It is also equipped with a safety control function that immediately stops the diagnosis if it detects low stability of 59 or less.

Three main factors influence the initial stability of the implant: implant design, surgical technique, and bone quality.[19] Bone quality is a variable related to patients, and the classification method proposed by Lekholm and Zarb,[20] classified as D1 to D4 according to the thickness of the cortical bone and the quality of the bone marrow, has been widely used to date. A greater thickness of the cortical bone is associated with lower micromovement of the implant. When the cortical bone is thin, the density of the bone marrow significantly affects the stability of the implant.[21] Recently, image data from CBCT have been used to evaluate the bone quality of the implant placement position before surgery, and changes in surgical techniques or implant design can be considered in advance to overcome this.[22]

Compared to implant design, primary stability is reported to be higher in tapered implant designs than that in cylindrical implant designs, especially when the bone quality is insufficient.[23-25] McCullough and Klokevold[26] compared the stability (ISQ value) of implants using traditional V-shaped threads and deeper and wider knife-edge threads. Their study reported that traditional thread-design implants had a steady decrease in stability during a 4-week follow-up period; however, the stability in deep and wide knife-edge thread-type implants were not significant for 4 weeks or increased in some implants. Other considerations for implant design include the form of the implant fixtures and abutments. Hermann et al.[27] reported that when one-piece implants and two-piece implants were compared, two-piece implants showed more crestal bone changes, which were caused by the micro-gap and micro-movement between the implant fixture and the abutment.

Several surgical techniques have been studied to overcome the poor bone quality of implant placement sites. Shadid et al.[28] reported in their systematic review that undersized drilling techniques, osteotome techniques, and flapless procedures can improve the primary stability of implants, especially the flapless procedure process, which can improve the primary and secondary stability of implants.

The MAGICORE® implant used in this study was designed to adopt a knife-edge-type thread with a tapered body. During implantation, a trephine burr-type drill capable of minimizing trauma to soft and hard tissues is used, and a tapping drill is used to maximize the contact area between the residual bone and the specially designed implant thread to increase the mechanical stability at the bone-implant boundary. In addition, since it has a one-piece body in which the fixture and the abutment are not separated, it is possible to prevent the resorption of crestal bone due to the micro-gap and micro-movement of traditional two-piece body implants, and no additional surgery is required to replace the implant abutment. Cuff sizes ranging from 2−5 mm with a machined surface above the alveolar bone can be selected, thereby promoting appropriate soft tissue recovery according to the amount of remaining soft tissue of the patient.

In case of implant prosthesis that has been implanted, the Magicore® implant uses a ferrulized crown-type prosthesis. This design reduces micro-movements and provides structural reinforcement that resists the functional force of the implant.[29]

The implants used in this study showed stable primary stability of −2 or lower in the case of PTV, ISQ of 53 or higher, and IST of 72 or higher in the bone marrow of D1−D3. However, since all three measurements of D4 showed low stability, it would be safe to consider surgical techniques (undersized drilling techniques, osteotome techniques, and flapless procedures) that can improve the initial stability of successful implants with poor bone quality, such as the posterior maxilla.

The primary stability of the implant decreased as the cuff size increased. Biomechanically, as the length above the implant fixture increases, the action of the type 1 lever increases, and it is believed that the implant mobility increases. In addition, Meridith et al.[30] reported that the supracrestal implant height and RFA value had a strong negative correlation, which is similar to the results of this study. However, the role of the cuff in MAGICORE® was designed to take consider the abutment of conventional two-piece implants and also secure the biological width without any surgical procedures in sloping bones or irregular alveolar ridges. Therefore, selecting the appropriate cuff size according to the condition of the soft and hard tissues will be helpful in the placement of successful implants.

In their in vitro study on the stability of implants, Arosio et al.[31] reported that a larger diameter of the implant and a longer length are associated with higher stability and that the increase in diameter stabilizes the implant more than the increase in length. Similarly, in this study, implants with diameters greater than 5.0 mm showed significantly higher primary stability, while implants with a length of 7 mm showed significantly lower stability than implants with a length greater than that. However, since additional surgical treatment to overcome insufficient bone quality is accompanied by the risk of failure and complications, implants with a short length and large diameter implants may be considered to ensure primary stability in these limited situations.

The MAGICORE® implant used in this study was first released in 2013; however, there is still little accumulation of experimental and clinical data. In addition, since the primary stability was compared using a single implant in this study, the difference from other implants under similar conditions could not be directly compared. Furthermore, stability evaluation of various additional clinical factors, such as placement location, number, and implant prosthesis form, are necessary along with long-term evaluation and primary stability in the early stages of implant placement.

Ⅴ. Conclusion

1. The mean PTV of the implants used in this study was -2.42 ± 4.98, the mean ISQ was 53.8 ± 11.3, and the mean IST was 71.8 ± 8.9.
2. The smaller the cuff size of the implant, the higher the primary stability.
3. The 11 mm long implants showed significantly higher primary stability in the three measurement methods used in this study.
4. The primary stability of an implant with a diameter of 5.0 mm or more was significantly higher than that of an implant with a diameter lesser than that.
5. Bone type and diameter of the implant had a greater influence on primary stability than the length of the implant and the length of the supracrestal height (cuff size in this study) of the implant.

Based on the results of this study, experimental and clinical studies should be continued to further strengthen the theoretical background and clinical significance of minimally invasive implants. Clinicians can identify the factors that affect the primary stability in implant procedures and select implants for minimally invasive implant surgery. Furthermore, MAGICORE® used in this study is an appropriate implant system for minimally invasive implant surgery with favorable primary stability.

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A Comparison of Implant Stability between Aggressive and Non-Aggressive Dental Implant Design Using Two Different Stability Measuring Techniques: In Vitro

Chanikarn Chaksupa[*, 1], and Atiphan Pimkhaokham[2]

[1]Esthetic Restorative and Implant Dentistry (International Program), Faculty of Dentistry, Chulalongkorn University, Bangkok, Thailand
[2]Department of Maxillofacial Surgery, Faculty of Dentistry, Chulalongkorn University, Bangkok, Thailand
[*]Corresponding author, E-mail:kloy2085@gmail.com

Abstract

Recently, implant thread design has been developed for purpose of achieving the proper primary stability. Also, a new device for evaluating implant stability has been introduced. However, the effect of aggressive thread design and the reliability of the device still lack knowledge. The aim of this in vitro study is to investigate the primary stability of aggressive thread design implant (BLX) compared with nonaggressive thread design implant (BLT) and to evaluate the correlation between implant stability quotient (ISQ) values and implant stability test (IST) values. Thirty-two implants were used in this study; sixteen implants were for each group. All implants were digitally planned and placed in 3D printed model with two edentulous premolar spaces using computer-assisted guided surgery. Postoperative implant stability measurement was performed immediately after implant insertion. Implant stability was measured by Osstell ISQ for ISQ value and AnyCheck for IST value. The data was analyzed using the Spearman correlation and Mann-Whitney U test. The mean ISQ value was 71.86 and 68.00, for BLX and BLT, respectively, while the mean IST value was 69.50 for BLX and 48.50 for BLT. In conclusion, the aggressive thread design implant (BLX) showed superior stability to the nonaggressive thread design implant (BLT) in both ISQ and IST groups. Moreover, there was a correlation between ISQ and IST in both implant designs.

Keywords: *implant stability, implant stability test, implant stability quotient, aggressive thread implant, non-aggressive thread implant*

1. Introduction

Implant stability is one of the most crucial factors for successful dental implant treatment. The satisfying stability during the healing period might prevent excessive micromovement and disruption of bone formation (Aspenberg et al., 1992). Primary stability is the stability of the implant at the time of implant placement, which is a critical factor for achieving osseointegration. Several possible aspects that have an influence on primary implant stability are bone-related factors, implant characteristics, and surgical technique (Atsumi, 2007; Meredith, 1998).

Since bone density or bone quality can determine the success in obtaining primary stability. Various bone assessments have been proposed, they were commonly classified into four bone types based on the compact bone to a trabecular bone ratio (Lekholm et al., 1985). According to Misch (1990), bone density can be categorized into D1 to D4, in which D1 comprised the majority of dense compact bone, D2 bone is composed of dense to the porous compact cortical bone on the outside and coarse trabecular bone on the inside, D3 bone is composed of porous, thinner cortical bone and fine trabecular bone, and D4 bone is composed of fine trabecular bone with very low density and little or no cortical crestal bone. The volume of available bone and its density are significantly correlated with the surgical intervention and implant type, and these factors are fundamental to the successful outcome of dental implant surgery. Recently, material which commonly use to replicate jaw bone for a mechanical-test in laboratory experiment is polyurethane foam block (Sawbones®; Pacific Research Laboratories Inc., Washington, USA). Polyurethane foam is generally accepted as the standard for mechanical testing of orthopedic implants. Furthermore, the physical properties of this biomechanical test material are uniform and consistent, preventing the variation which can occur when

testing with human cadaver bone (Devlin et al., 1998). In addition, some in vitro study has been striving to achieve the utmost simulation of the intraoral implant surgery and decrease the limitations. The three-dimensional printing models with the edentulous area were used and attached to the phantom head, to mock a real intraoral surgery, also position and visualization of the operator (Sittikornpaiboon et al., 2021; Yeung et al., 2020).

Regarding surgical technique, optimal implant placement is critical for providing a prosthesis design that is suitable for long-term success and maintenance. The conventional guide technique provided an acceptable outcome by using a surgical stent that was converted from a radiographic stent with an opaque radiographic marker. The stents enable the surgeon to observe the appropriate prosthesis location intraoperatively. This technique is frequently referred to as a free-hand technique. However, the exact implant position is highly dependent on the surgeon's ability and expertise in this technique. Lately, new digital technology called static computer-assisted implant surgery (CAIS) has been used to plan implant position and design surgical guided stent before surgery, considering the bone quality and quantity, the location of important anatomical structures, soft tissues, and teeth, and the final prostheses. A 3D-printed surgical guide is used to transfer the planned implant location to the surgical site. Through a metal sleeve placed in the surgical guide, guided surgical drills control the angulation and depth of the implant osteotomy. Moreover, it has been stated that guided implant surgery has higher precision and accuracy than conventional surgical guides or free-hand implant surgery (Smitkarn et al., 2019; Yeung et al., 2020).

Another potential factor that can influence the stability of the implant and long-term success rate is implant characteristics. The main features of the implant are such as implant material, implant micro-design, and macro-design (Bolind et al., 2005; Huang et al., 2008). Currently, new material has been developed, which is a hybrid of titanium and zirconia. According to the study by Kobayashi et al. (1995), it provides greater strength and biocompatibility. As a result, the risk of fracture is reduced, allowing the dentists to choose a smaller diameter implant in case of anatomical limitations. Moreover, most implant companies offer taper implants, due to the advantage of lateral compression in poor bone implant sites and situations with anatomical limitations. Currently, the aggressive thread design was introduced. This implant design provides a special ability to cut the bone during insertion and obtain better primary stability after implant placement (Irinakis & Wiebe, 2009).

To determine or predict the outcome of implants, various techniques for evaluating implant stability have been developed, including invasive and non-invasive clinical test methods. Insertion torque (IT) is one of the objective and non-invasive measurement techniques. Some studies have previously reported implant stability using IT measurements (Akca et al., 2010; O'Sullivan et al., 2004). Implant stability could be determined by a high torque number (Ncm). However, following implantation, this procedure could not be reproduced. Consequently, Resonance frequency analysis (RFA) was introduced. RFA is a non-invasive electronic instrument that has excellent repeatability and reliability for monitoring changes in implant stability (Meredith, 1998). The implant-bone complex's stiffness was determined and reported as an implant stability quotient (ISQ) value ranging from 1 (least stability) to 100 (highest stability). In the last decade, the RFA has been employed increasingly to provide a quantitative assessment of implant stability. ISQ measurements were taken periodically throughout the healing period to detect changes in implant stability as a result of successful osseointegration. (Bischof et al., 2004; Huwiler et al., 2007; Meredith et al., 1997; Nedir et al., 2004). However, in the process of ISQ measurement, the healing abutment must be unscrewed and the transducer of a metal rod (a peg) must connect to the implant. As a result, the routine of unscrewing the healing abutment and a peg back and forth may affect implant stability and osteointegration during a critical period.

Consequently, an implant stability test (IST) device (AnyCheck: Neobiotech, Korea) has been developed to detect the stiffness between alveolar bone and implant by means of slightly tapping at the healing abutment. AnyCheck can also be utilized without having to unscrew the healing abutment. It strikes the healing abutment six times over three seconds and converts the time into IST values. As a result, this device provides a safety measure for detecting initial implant stability, however, research on AnyCheck is limited, and more studies are needed (J. Lee et al., 2020).

However, none of the studies that have assessed primary stability using the ISQ and IST values have investigated the impact of the aggressive thread implant. The advantages of identifying factors affecting implant stability are substantial. It will enable clinicians to select an implant that minimizes or eliminates implant instability during the early stages of bone remodeling, allowing a greater number of cases to meet the criteria for immediate or early loading while maintaining a high degree of predictability and a successful treatment outcome.

2. Objectives

1. To investigate the primary stability of aggressive thread design implant (BLX) compared with the nonaggressive thread design implant (BLT)
2. To evaluate the correlation between implant stability quotient (ISQ) values and implant stability test (IST) values.

3. Materials and Methods

Materials

Polyurethane blocks

Rigid polyurethane blocks (Sawbones®; Pacific Research Laboratories Inc., Washington, USA) were utilized at various densities to represent bone in a laboratory setting. The American Society for Testing Materials recommends using synthetic polyurethane foams as a standard material for mechanical testing of orthopedic devices and equipment because they have a density and mechanical qualities comparable to human bone. Following Misch's classification of bone density, polyurethane blocks at a density of 40 pounds per cubic foot (PCF) were represented as D1 bones, polyurethane blocks at a density of 30 PCF were represented as D2 bones, polyurethane blocks at a density of 20 PCF were represented as D3 bones, and polyurethane blocks at a density of 10 PCF were represented as D4 bones. All blocks were standardized using the same batch and weighed accurately. To imitate mixed cancellous bone at the implant insertion site, each density of polyurethane blocks was cut into a cylindrical shape and randomly stacked.

Implants

The implant used in this study is BLT Straumann® dental implant system and BLX Straumann® dental implant system (Straumann®, Switzerland). Every single placed implant is Roxolid® with SLActive® surface. All implants were placed by using digital guided surgery, according to a standardized surgical protocol following the manufacturer's instructions.

Methods

Model preparation

The method was adapted from a previously published study by Sittikornpaiboon et al. (2021); Yeung et al. (2020). This research used a subject with bilateral edentulous sites at the maxillary first premolar. To create a suitable digital U shape full-arch model with a bar, an intra-oral scan file (Standard Tessellation Language; STL) was created and uploaded into Meshmixer software version 3.5.474 (Autodesk Inc., California). At both edentulous sites, a cylindrical hollow space of 7 mm in diameter and 16 mm in length was designed to conform to the implant implantation locations. Thirty-two digital models were produced using a 3D printer (Straumann CARES P30+, Straumann AG, Basel, Switzerland) using a model resin solution (P Pro Master Model Gray, Straumann AG, Basel, Switzerland) with a layer thickness of 0.05 mm. Afterward, the models were completely cleaned with isopropyl alcohol and treated with UV light to cure. To replicate mixed cancellous bone at the implant insertion site, the hollow area at each site was packed with a computer-generated randomized pattern of four different kinds of polyurethane blocks (Sawbones, Washington, United States); each density of polyurethane blocks was cut into a cylindrical form of 7 mm in diameter and 4 mm in length, according to the total height of the hollow space. Each polyurethane piece was randomly stacked up into four layers, to mimic diverse bone densities in different areas of the human bone jaw. The polyurethane was ensured to fit completely in the hollow space and secured to the model by using cyanoacrylate glue. A computer-generated randomization list was carried out by a statistician who was not

engaged in implant planning design or placement and each model was given a number from 1 to 32. All 32 models were chosen for the procedure in order from 1 to 32.

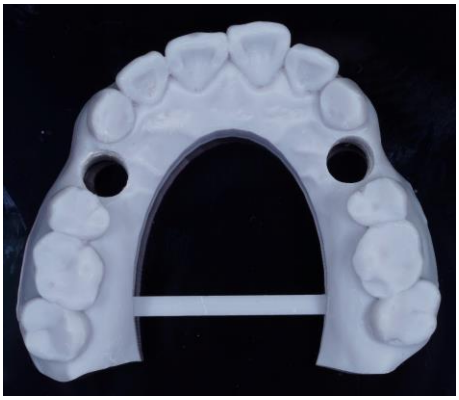

Figure 1 Sample of U shape full-arch model with bilateral edentulous sites at the maxillary first premolar

Implant planning procedure

Each implant was digitally planned and a surgical guide was created on a software (coDiagnostiX software version 9.7, Dental Wings GmbH, Chemnitz, Germany) using Digital Imaging and Communications in Medicine (DICOM) file and STL file. To create a DICOM file, all models' imaging data were taken using a cone-beam CT (CBCT) machine (X- mind Trium, de Götzen S.r.l.-Acteon Group, Varese, Italy). The CBCT machine was set to 6 mA, 86 kV, 54 seconds exposure time, 0.15 mm voxel size, and 80 x 80 mm field of view. Moreover, the models were then scanned for 3D files, using a desktop scanner (Cares 7 SERIES, Dentalwings, Montreal, Quebec, Canada) to create an STL file. Thirty-two implants were determined a final planned position on the software. All implants were planned by one investigator. The optimal position placed at the center of the polyurethane block: 1.5 mm of the surrounding area, measured from implant shoulder to outer margin of the block and 2 mm deeper from the top of the block. 16 implants for each of the two drilling protocols. Each protocol specifies the particular surgical kit, the sleeve height, the sleeve location, and the implant design. All 32 surgical guides were designed with an embedded guide sleeve, to achieve the optimal implant position and angulation in all subjects and to control the error from the 3D printing process of the model. Additionally, implant diameters varied slightly between the two groups, owing to the variance in implant diameter available throughout various systems. The implant length was set to ensure that all groups had the same free-drilling-distance length. As a result, two distinct procedures were used: group A used a 4.1 x 12 mm bone level tapered implant (Straumann AG, Basel, Switzerland), while group B used a 4.0 x 12 mm BLX implant (Straumann AG, Basel, Switzerland).

The surgical guides were generated identically using the coDiagnostiX program. All 32 surgical guide templates were created with four inspection windows. Between the surgical guide and the tooth, a gap of 0.05 mm was established. All surgical guides were printed using a 3D printer (Straumann CARES P30+, Straumann AG, Basel, Switzerland) with a layer thickness of 0.1 mm from a 2 mm thick medical grade surgical guide resin material (P Pro Surgical Guide, Straumann AG, Basel, Switzerland).

Surgical protocol

The models were attached to a phantom head in a supine position, in order to simulate the real procedure in the patient. The operator is seated in the right rare position. The surgical guide was placed on a model and evaluated the fitting through the inspection window before the implant placement procedure. All guided implant surgeries were conducted by one operator. The two drilling systems were applied in this experiment. The same design of implant used the same protocol. The drilling procedure was carried out following the manufacturer's instructions. Using each system's guided adapter, the implants were inserted fully guided. The BLX was placed at the upper left premolar area while the BLT was placed at the upper right premolar area.

Outcome measurement

All measurements were performed by one trained evaluator. After implants were placed, the final insertion torque value (Ncm) was recorded immediately. Implant stability was measured by an Osstell ISQ. A standardized SmartPeg was hand-screwed into the implant fixture with an amount of 4-5 Ncm of torque which means 'finger tighten' or 'finger torque' as the manufacturer's recommendation. The probe of the device was held close as much as possible to the peg in the buccal and mesial direction. The space between the probe's tip and the top of the SmartPeg should be a few millimeters without touching. Another measurement of implant stability was used by using AnyCheck IST device with a standard height of healing abutment of 4 mm (AnyCheck: Neobiotech, Korea). This device needs to maintain the contact angle between 0 to 30 degrees downward based on the ground level (Figure 2). The measurement was performed at the buccal and lingual aspects of the healing abutment. The ISQ and IST measurement was performed 3 times separately on each side.

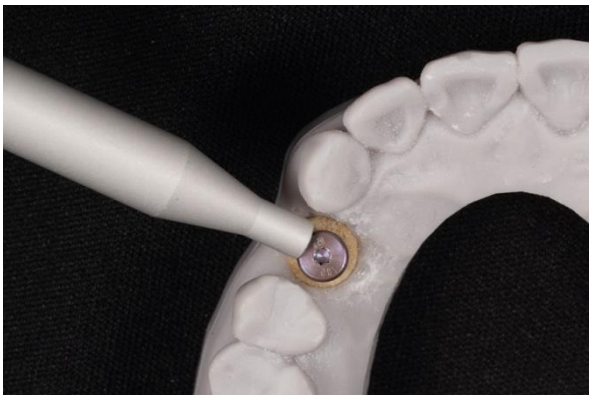

Figure 2 AnyCheck device needs to maintain the contact angle between 0 to 30 degrees downward based on the ground level

Statistical analysis

The data were analyzed with IBM SPSS Statistics software version 22 (SPSS Inc., Chicago, Illinois). Shapiro-Wilk test verified the non-normality of the data distribution. Thus, the Spearman correlation test was used to analyze the correlation between the ISQ value and IST value. P values <.05 were set as statistically significant. Mann-Whitney test was used to compare the implant stability of BLX and BLT.

4. Results and Discussion

4.1 Results

A total of 32 implant sites in 16 models were included in this study. 16 BLT Straumann® dental implants and 16 BLX Straumann® dental implants were placed in each model. The mean implant stability value and standard deviations were shown in Table1. The mean ISQ value was 71.86 and 68.00, for BLX and BLT respectively. Also, the mean IST value was 69.50 for BLX and 48.50 for BLT (Figure 3).

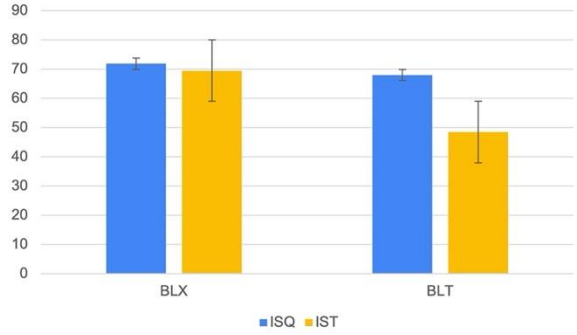

Figure 3 Mean ISQ and IST value of BLX and BLT implant

Regarding the implant type, the implant stability between BLX and BLT was analyzed by the Mann-Whitney test and found statistical differences in both ISQ value and IST value (p-value <0.001) (Table 1).

Table 1 The implant stability in each group

Group	BLX	BLT	P-value*
ISQ			<0.001
Mean	71.68	68.00	
Median	71.50	69.50	
Std. Deviation	3.36	3.97	
Min-Max	66.00-77.00	59.00-72.00	
Range	11	13	
95% CI	69.90,73.48	65.89,70.11	
IST			<0.001
Mean	69.50	48.50	
Median	70.00	48.50	
Std. Deviation	3.43	6.39	
Min-Max	63.00-74.00	40.00-57.00	
Range	11	17	
95% CI	67.61,71.33	45.10,51.90	

**Differences between BLX and BLT were analyzed using the Mann-Whitney U test*

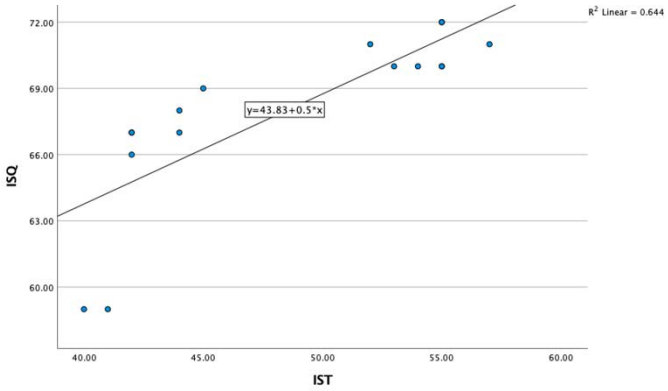

Figure 4 Correlation between ISQ and IST in BLT

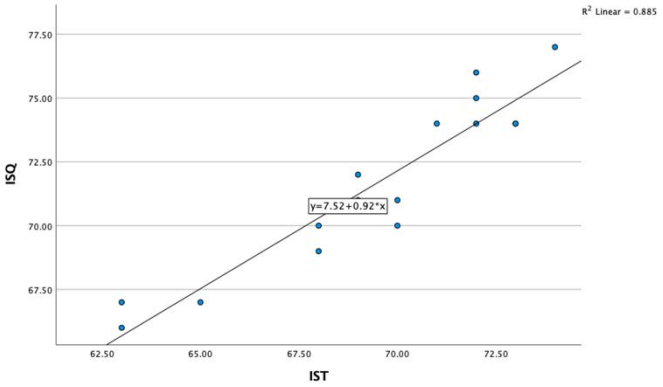

Figure 5 Correlation between ISQ and IST in BLX

The correlation between ISQ value and IST value was found in both implant types (p-value < 0.001) as shown in figure 4, and Figure 5. Besides, the ISQ value has been found to have a higher number than the IST value in both implant designs.

4.2 Discussion

This study aimed to investigate the primary stability of aggressive thread design implant (BLX) compared with the non-aggressive thread design implant (BLT) and evaluate the correlation of implant stability quotient (ISQ) values and implant stability test (IST) values. Resonance frequency analysis (RFA) was introduced by Meredith et al. (1996) and has been commonly used as a non-invasive electronic device that is a reliable and repeatable tool for assessing implant stability during the healing process. The RFA analyzes the implant-bone complex stiffness and displays it as an implant stability quotient (ISQ) value. The ISQ value is determined by three key factors: the transducer design, the stiffness of the implant-bone junction (implant characteristics, cancellous to cortical bone ratio, and implant-tissue interface stiffness), and the total effective length (Sennerby & Meredith, 1998).

Implant body design and surface modifications have been proposed to increase implant success in low-quality bone by improving anchoring and giving a larger surface area of load to alleviate stress on softer bone types. According to a finite element analysis study, the distributions and magnitudes of bone stress might vary depending on the implant geometry. Additionally, threads are employed to optimize initial contact, enhance stability, increase the surface area of the implant, and facilitate the absorption of interfacial stress. Moreover, according to Lozano-Carrascal et al. (2016), conical implants achieve higher ISQ values and insertion torque values than cylindrical design implants. Rokn et al. (2011) suggested that tapered implants gain more lateral compressive force on the surrounding bone, thus in the area with inadequate bone quality and quantity, the tapered implant is recommended to achieve better primary stability.

Regarding the macro-design of implants, this present study showed the difference between the two implant designs. The aggressive thread design has been determined to have a greater ISQ value and IST value, which agrees with the study by McCullough and Klokkevold (2017). It has been shown that macro-thread design affects implant stability; indicating the novel knife-edge design implant had an overall higher mean ISQ value compared to a standard V-shape design. Moreover, the previous studies reported the highest ISQ value in NobelActive which interestingly created extensive grooves in the apical part, while the imprint was considerably smaller for BLT and Astra (Karl & Irastorza-Landa, 2017). The aggressive thread design implant presented the advantage in fresh socket extraction of non-molar teeth cases resulting in a very high initial stability (Irinakis & Wiebe, 2009).

The result showed that there was a significant correlation between ISQ value and IST value in both BLX and BLT groups. Moreover, a study by D. H. Lee et al. (2020) has reported similar results, the IST

values were strongly correlated with ISQs, suggesting that the IST values follow the tendency of ISQ values. Also, there was no information about appropriate healing abutment diameter for *in vitro* or clinical settings.

Currently, The Osstell ISQ device has been increasingly performed in clinical research to evaluate the development of implant stability during the healing periods. The ISQ tends to vary when the contact of the bone-implant is not strong or certain. On the other hand, when an implant has attained osseointegration and the contact of the bone-implant is firm, this device seems to be rather reliable. Furthermore, while assessing implant stability with the Osstell ISQ, the uppermost part of the fixture (cover screw or healing abutment) must be removed and the SmartPeg connected, which may create difficulty and limitations (Friberg et al., 1999; Nedir et al., 2004). However, since the AnyCheck does not require unscrewing the healing abutment, the procedure is less difficult than with the Osstell ISQ. Also, the measurements of the newly built AnyCheck device were consistent with ISQ values, the AnyCheck device values range from 1 to 99. Moreover, the tapping motion was optimized by using shorter tapping intervals and applying less force to the implant, resulting in a more secure method of determining implant stability.

Besides, computer-assisted implant surgery (CAIS) was utilized in this study for controlling the position of the implant in every model and guaranteed that all implants would be placed in the cylindrical polyurethane block. According to Smitkarn et al. (2019), the static CAIS showed significantly less deviation than free-hand surgery in all parameters. Six out of nine measurements were shown remarkably higher accuracy in the CAIS group. Moreover, in a split-mouth study by Farley et al. (2013), inserted implants using the CAIS technique were found to be more accurate in all dimensions compared to implants placed conventionally. However, the authors stated that a limitation of the research was the fit of the CAD/CAM guides, some of which required relining with the transparent acrylic resin prior to surgery. Therefore, in this study, the surgical guide was individually created and confirmed fitting in advance of the procedure to eliminate the instability of the guide.

The limitation of this in vitro study was the research design of this in vitro investigation did not allow for comparison of the devices in osseointegrated implants, and more in vivo studies are necessary before the devices may be used in clinical settings. The correlation between the devices may reflect tendencies toward implant stability, but it cannot provide precise numbers indicating implant prognosis since the devices are not connected. Further research is needed to determine the reliability of the AnyCheck device in clinical settings.

5. Conclusion

According to the result of this study, the aggressive thread design implant (BLX) showed superior stability to the nonaggressive thread design implant (BLT) in both ISQ and IST groups. Moreover, within the limitation of this study, we conclude that there was a correlation between ISQ value and IST value which the ISQ value was higher than the IST value in both implant designs.

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Analysis and interpretation of data: Nikos Mattheos. Statistical analysis: Soranun Chantarangsu. Study supervision: Nikos Mattheos.

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BMC Oral Health

RESEARCH Open Access

Validation of an implant stability measurement device using the percussion response: a clinical research study

Yurie Okuhama[1], Koudai Nagata[1], Hyunjin Kim[1], Hayato Tsuruoka[1], Mihoko Atsumi[2] and Hiromasa Kawana[1*]

Abstract

Background: Several devices have been developed to measure implant-bone stability as an indicator of successful implant treatment; these include Osstell®, which measures the implant stability quotient (ISQ), and the more recent AnyCheck®, which relies on percussion for the implant stability test (IST). These devices make it possible to measure implant stability. However, no studies have compared the performance of AnyCheck® and Osstell® (i.e., IST and ISQ values) in clinical practice. Therefore, this study aimed to determine the correlation between primary and secondary implant stability using the Osstell® and AnyCheck® devices.

Methods: Ten patients (7 women; age [mean ± standard deviation]: 49.1 ± 13.3 years) with partially edentulous jaws who received a total of 15 implants were included. IST (AnyCheck®) and ISQ (Osstell®) values were measured immediately after implantation and at 1, 2, 3, 4, and 6 weeks post-implantation. Each measurement was performed three times, and the average value was used as the result. The correlation between measurements obtained using the two devices was determined using Spearman's rank correlation coefficient.

Results: The IST values ranged from 79.1 ± 2.87 to 82.4 ± 2.65. The ISQ values ranged from 76.0 ± 2.8 to 80.2 ± 2.35. Spearman's rank correlation coefficient was r = 0.64 immediately after implantation, r = 0.29 at 1 week, r = 0.68 at 2 weeks, r = 0.53 at 3 weeks, r = 0.68 at 4 weeks, and r = 0.56 at 6 weeks. A positive correlation was found in all cases, except at week 1 when the correlation was weak; the IST and ISQ values decreased the most during the first postoperative week and increased during the second week. The IST values were also slightly higher at all measurement points.

Conclusion: The ability to assess implant stability without removing the abutment during healing is essential for determining the timing of loading without the risk of bone resorption. The results of this study suggest that AnyCheck® is useful for determining primary and secondary implant stability.

Keywords: Dental implant, Implant stability quotient (ISQ), Implant stability test (IST), AnyCheck®, Osstell®

Background

In recent years, the use of dental implants has become widespread in the field of dentistry, and various technological advancements have been proposed to improve treatment outcomes [1–3]. For instance, several devices have been developed to measure implant stability as an indicator of the success of implant treatment. The Osstell® device [4] allows the measurement of the implant

*Correspondence: kawana@kdu.ac.jp

[1] Department of Oral and Maxillofacial Implantology, Kanagawa Dental University, 82 Inaoka-cho, Yokosuka, Kanagawa 238-8580, Japan
Full list of author information is available at the end of the article

stability quotient (ISQ) using the resonance frequency analysis (RFA) method, whereas the Periotest® device [5] uses the percussion method. More recently, the AnyCheck® device, which also relies on the percussion method, has been developed [6]. Importantly, the insertion torque (IT) of the implant into the bone influences the success of implant treatment; therefore, the ability of these devices to quantify and evaluate implant stability has contributed greatly to the success of implant treatments [7, 8], benefitting both dentist and patients. There are two types of implant surgery: those that allow submerged implant healing and those with non-submerged implant healing. Submerged implant healing is often considered when the primary stability is poor or when bone grafting has been performed [9]. In non-submerged implant healing, removal of healing abutments prior to superstructure placement has been reported to be a cause of accelerated bone resorption [10]. Therefore, the concept of "one abutment–one time," in which the abutment is placed immediately after implantation to control bone resorption, is popular [11]. Despite its long history of use, the Osstell® device requires removal of the healing abutment and the attachment of smart pegs. Of note, AnyCheck® does not require the healing abutment to be attached or removed; therefore, it can measure implant stability without promoting bone resorption. Although there have been various reports on implant stability, thus far, no study has compared the ISQ and implant stability test (IST) values in clinical practice [12]. To address this gap in knowledge, the present study aimed to investigate the correlation between implant stability for the Osstell® and AnyCheck® devices.

Materials and methods

Patients

Ten patients (7 women, 3 men) with partially edentulous jaws who underwent implant treatment at our university hospital (n = 15 implants) were included in this study. The mean age (± standard deviation) was 49.1 ± 13.3 years. Patients were selected based on absence of systemic diseases, smoking status (non-smokers), and non-requirement of bone grafting. The IT was set at 35 Ncm using micromotor and torque wrench for all patients. Healing abutments of the following diameters were attached to the implants: 2 mm in one implant, 4 mm in nine, and 6 mm in five implants. This study was approved by the institutional ethics committee of our hospital (approval #739), and written informed consent was obtained from all patients.

Surgical procedure

All patients were instructed to take an oral dose (1 g) of amoxicillin hydrate (Sawacillin Capsules®; LTL Pharma, Tokyo, Japan) 1 h before surgery. After administration of the anesthetic (Lidocaine/Adrenaline bitartrate®; Showa Yakuhin Kako Co., Ltd., Tokyo, Japan), the alveolar mucosa, including the periosteum, was incised at the top of the ridge and separated. After drilling, implants were placed according to the implant system protocol; the torque and depth of placement were adjusted with a torque ratchet. All implant placements were performed via freehand insertion; additionally, all surgeries were performed in a non-submerged fashion. The implant system used was Straumann® SLActive ϕ 4.1 × 10 (bone level tapered implant; Basel, Switzerland). All surgeries were performed by the same doctor, a teaching Associate in the Department of Implantology at our university hospital.

Measurement of the IST and ISQ values

The IST values were measured using the AnyCheck® device (Neobiotech Co., Ltd., Seoul, South Korea) (Fig. 1). The bone-to-implant stability index was set based on the ISQ values (0–59, not recommended for loading; 60–99, good stability, recommended for loading); the IST and ISQ have similar reference values. Osstell® was used instead of Periotest® in this study. Briefly, to determine the IST value, the healing abutment was struck six times over 3 s, and the contact time

Fig. 1 The AnyCheck® implant stability test (IST) device

with the healing abutment was measured to calculate the stability. Notably, in accordance with the manufacturer's recommendations, the patient was placed in an upright position during measurement, and the contact angle was set at 0°–30°. Since AnyCheck® uses a standard healing abutment height of 4 mm, values for healing abutment heights other than 4 mm were corrected as recommended by the manufacturer (Table 1).

The ISQ values were determined using the Osstell® ISQ device (Integration Diagnostics Ltd., Goteborgsvagen, Sweden) (Fig. 2). In principle, magnetic pulses based on the RFA method stimulate and resonate the smart peg (Integration Diagnostics Ltd.) attached to the implant body in the patient's mouth, making it possible to quantify stability. At the time of measurement, the intraoral healing abutment was removed, and the smart peg was attached to the implant body via hand tightening.

Both the IST and ISQ values were measured immediately after implantation and at 1-, 2-, 3-, 4-, and 6-weeks post-implantation. Each measurement was taken three times, and the mean was used as the definitive result. The ISQ was measured following assessment of the IST. For all implants, impressions were obtained at 4 weeks after placement, and provisional restorations were placed at 6 weeks. All measurements were taken by the same dental surgeon.

Statistical analyses

Correlations between the IST and ISQ values were assessed using BellCurve for Excel (Social Survey Research Information, Inc., Tokyo). Spearman's rank correlation coefficients were used to determine correlations.

Sample size was calculated by one-way analysis of variance using G-Power (version 3.1.9.2). The sample size required to obtain 80% of the effect size of 0.4 at $\alpha = 0.05$ was calculated.

Table 1 Corrected IST values, measured using the AnyCheck® device, based on the healing abutment height

Healing abutment height (mm)	IST value
7	+6
6	+4
5	+2
4	±0
3	−2
2	−4
1	−6

IST, implant stability test

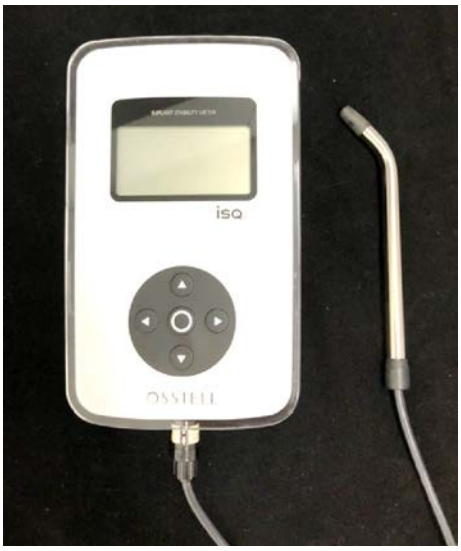

Fig. 2 The Osstell® implant stability quotient (ISQ) device

Results

The IST values immediately, 1 week, 2 weeks, 3 weeks, 4 weeks, and 6 weeks after implantation were 81.0 ± 2.82, 79.1 ± 2.87, 79.7 ± 2.83, 80.5 ± 2.71, 80.9 ± 4.0, and 82.4 ± 2.65, respectively. The ISQ values immediately, 1 week, 2 weeks, 3 weeks, 4 weeks, and 6 weeks after implantation were 79.8 ± 2.89, 76.0 ± 2.8, 77.8 ± 2.63, 79.2 ± 2.44, 79.7 ± 2.77, and 80.2 ± 2.35, respectively (Fig. 3). Of note, both the IST and ISQ values decreased the most in the first week after surgery and increased in the second week; additionally, the IST value was slightly higher at all measurement points. The Spearman's rank correlation coefficients for each measurement period were as follows: r = 0.64 immediately after implantation; r = 0.29 at 1 week; r = 0.68 at 2 weeks; r = 0.53 at 3 weeks, r = 0.68 at 4 weeks, and r = 0.56 at 6 weeks. A positive

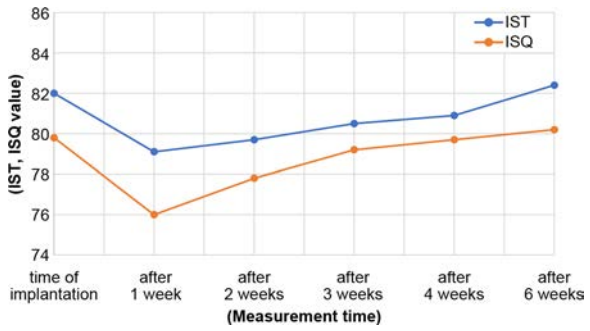

Fig. 3 Comparison of the mean implant stability test (IST) and implant stability quotient (ISQ) values at different times post-implantation

correlation was found in all cases, except at 1 week when the correlation was weak (Fig. 4).

Discussion

This study compared the changes in implant stability using the Osstell® and AnyCheck® devices. Our analysis indicated that the measurements exhibited a positive correlation of > 0.5, except after 2 weeks. This suggested that AnyCheck® had the same performance as Osstell®.

When the IT is high, bone resorption is promoted. Optimization of the IT is considered the key to successful implant treatment [13–15]. In this study, all the implants had an IT of 35 Ncm. However, even in cases of low IT, the use of AnyCheck® allows safe assessment of implant stability. The IST and ISQ values in this study were high. Zwaan et al. [16] placed 163 implants in the maxilla and compared the IT at 50 Ncm, 40–45 Ncm, 30–35 Ncm, and ≤ 30 Ncm and found that the ISQ values were 76.2 ± 5.3, 72.3 ± 5.3, 70.0 ± 6.7, and 68.1 ± 6.2, respectively. The ISQ values were also reported to be higher for tapered implants than for straight implants. Van Eekeren et al. [17] compared bone-level with tissue-level implants and revealed that the ISQ values (at the time of placement and 2, 3, and 12 weeks postoperatively) were 77.8, 75.6, 76.3, and 79.1, and 74.0, 71.8, 72.6, and 76.8, respectively. Importantly, the above results suggest that ISQ values tend to vary according to bone quality, implantation site, and implant shape, in line with the findings reported elsewhere [18]. As reported above, the authors of this study think that the high value was due to the use of bone-level and tapered implants. Oates et al. [19] reported that the stability of SLActive® implants changed from a decrease to an increase at 2 weeks after placement, in line with our results. In the present study, the weakest correlation was observed after 2 weeks. This may be explained by individual differences in the decline of primary stability, resulting in large differences in IST and ISQ.

Park et al. [6] placed an implant into an artificial bone block to verify the accuracy of AnyCheck®; interestingly, the stability decreased as the height of the healing abutment increased and as the contact angle decreased from 30° to 0° (perpendicular to the long axis of the implant and parallel to the ground). Subsequently, Lee et al. [20] placed implants at 10 N, 15 N, and 35 N into artificial bone blocks together with five different diameters of healing abutments of the same height, measured the IST values using AnyCheck®, and compared them with the ISQ values determined using Osstell®. Importantly, they reported that the diameter of the healing abutment did not affect the ISQ and IST values, which exhibited a strong correlation. Consistent with these results, Lee et al. [21] also found that the results for the AnyCheck® and Osstell® devices were correlated in the context of both internal-connection and external-connection implants (within pig bone). Of note, they also reported that the IST values were higher for both implants and that there was no significant difference between the IST and ISQ values. However, neither the IST nor the ISQ values are known to be accurate; they should only be considered as one among several indicators.

In clinical practice, Al-Jamal et al. [22] demonstrated that there was a significant correlation between primary stability and IT using the AnyCheck® device in the context of 40 implants. However, they did not compare their findings with measurements obtained using the Osstell®

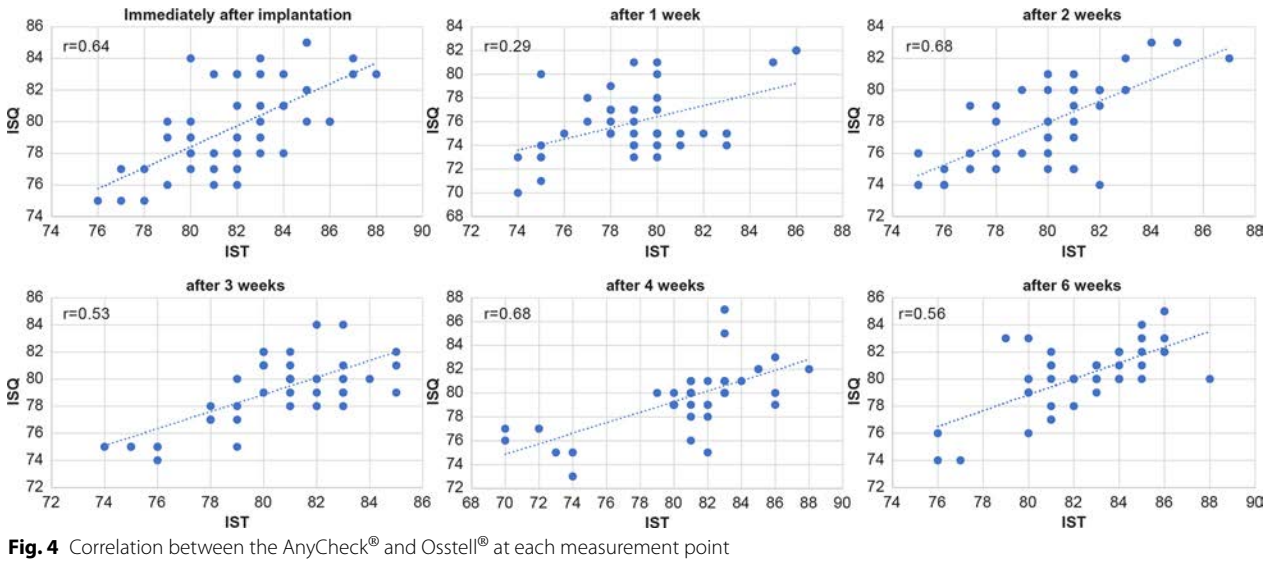

Fig. 4 Correlation between the AnyCheck® and Osstell® at each measurement point

device. The present study is the first in which the IST and ISQ values were measured and compared weekly in clinical practice, from immediately after implantation to 4 weeks later. While the Osstell® is a device with a long history of use and has been explored in many studies to date, its use requires removal of the healing abutment and attachment of the smart peg. The recently released Osstell Beacon® is cordless. However, as before, it still requires a smart peg, and the healing abutment must be attached and removed. Esposito et al. [23] reported that the removal of the healing abutment (three times after implantation until the time of superstructure attachment) led to 0.16 mm of bone resorption per year (*versus* non-removal of the healing abutment). Similar results were obtained by Bressan et al. [24]—0.43 mm of bone resorption over 3 years in healing abutment removal *versus* non-removal contexts—as well as by Koutouzis et al. [25]—0.13 mm versus 0.28 mm bone resorption in 6 months after implantation in the without versus with healing abutment removal context). Importantly, AnyCheck®, which allows the measurement of stability without the need to attach or to detach the healing abutment, reduces bone resorption and can be applied to low-torque cases. In the present study, a positive correlation of > 0.5 was observed at all measurement points, except after 2 weeks. Considering the risk of bone resorption and other factors, the AnyCheck® is expected to perform as well or better than the Osstell®. Since there are no reports comparing the two devices in clinical practice, further validation of this matter is necessary. Furthermore, this study has some limitations. The sample size for this study was small. This was due to the limited number of patients in whom implants of the same system, diameter, and length were placed. In addition, in vitro studies cannot assess changes in implant stability over time. Therefore, studies using models could not be conducted previously. In the future, it is necessary to distinguish between bone quality and implant diameter to obtain more detailed data.

Conclusion

The ability to assess implant stability without removing the abutment during healing is essential for determining the time at which load can be applied without the risk of bone resorption. Altogether, our results suggest the similar performance of Osstell® and AnyCheck®, and, consequently, the usefulness of the latter for the determination of implant stability.

Abbreviations

ISQ: Implant stability quotient; RFA: Resonance frequency analysis; IT: Insertion torque; IST: Implant stability test.

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Not applicable.

Author contributions

HK, KN conceived the idea and designed the study. YO performed the research. HT, HjK analyzed the data. MA contributed with new methods or models. YO wrote the paper. All authors have read and agreed to the final version of the manuscript.

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Availability of data and materials

The datasets generated and/or analyzed during the current study are not publicly available due to privacy and ethical concerns but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study was approved by the Kanagawa Dental University Ethics Committee (approval # 739), and written informed consent was obtained from all patients. All methods were performed in accordance with the 1964 Helsinki Declaration.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Author details

[1]Department of Oral and Maxillofacial Implantology, Kanagawa Dental University, 82 Inaoka-cho, Yokosuka, Kanagawa 238-8580, Japan. [2]Department of Fixed Prosthodontics, Kanagawa Dental University, 82 Inaoka-cho, Yokosuka, Kanagawa, Japan.

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Clinical Validation of Dental Implant Stability by Newly Designed Damping Capacity Assessment Device during the Healing Period

Ho-Kyung Lim [1,†], Sung-Jae Lee [2,†], Yujin Jeong [3], Jong-Seok Lee [4], Jae-Jun Ryu [4], Ji-Suk Shim[5,*] and In-Seok Song [2,*]

[1] Department of Oral & Maxillofacial Surgery, Korea University Guro Hospital, Seoul 08308, Korea
[2] Department of Oral & Maxillofacial Surgery, Korea University Anam Hospital, Seoul 02841, Korea
[3] Department of Biostatistics, Korea University College of Medicine, Seoul 02841, Korea
[4] Department of Prosthodontics, Korea University Anam Hospital, Seoul 02841, Korea
[5] Department of Prosthodontics, Korea University Guro Hospital, Seoul 08308, Korea
* Correspondence: shoss@hanmail.net (J.-S.S.); densis@korea.ac.kr (I.-S.S.)
† These authors contributed equally to this work.

Abstract: *Background and Objectives:* To evaluate the stability of a dental implant and the effectiveness of a newly designed damping capacity assessment device by improving the number of blows and strength evaluated by a prospective clinical study. *Materials and Method:* The stability of dental implants was measured in 50 implants in a total of 38 patients. Measurements were performed using Anycheck and Periotest M devices, twice in total, divided into buccal and lingual directions. In addition, measurements were performed on the day of surgery, two weeks, one month, two months, and three months after surgery for a total of five times. After the standardization of the measured values, the differences and changes over time for each device were observed. *Result:* No difference in standardized values between the two devices was observed at any time point. In both devices, stability decreased at two weeks postoperatively but gradually increased thereafter. No differences were observed in the values according to the measurement direction. *Conclusions:* The damping capacity of Anycheck was similar to that of Periotest M. After a slight decrease in stability two weeks after implant placement, implant stability increased over time.

Keywords: dental implants; stability; dentistry; analytic device

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1. Introduction

Osseointegration of dental implants is affected by various factors such as the type of implant surface, density of the alveolar bone, age of the patient, whether or not a bone grafting is performed, and the volume of the alveolar bone [1]. Various methods of measuring the stability of dental implants have been used in clinical practice. The insertion torque value measurement method, such as the Osstell method using resonance frequency analysis (Osstell device, Integration Diagnostics AB, Sa¨vedalen, Sweden), and Periotest M method using damping capacity assessment (Periotest M device, Gulden Messtechnik, Bensheim, Germany) have been widely used [2–4]. Each measurement method has its characteristics. Osstell is a non-contact measurement method, and its measurement values are internationally standardized. However, a separate measuring device (Smartpeg) is required, and there is a risk and inconvenience in releasing the healing abutment for the measurement. Periotest M is convenient and safe for measuring the stability of a healing abutment. However, the measured value is affected by the angle of impact and the high strength of the blow, and the number of blows is rather high (16 times) causing a feeling of rejection in the patient.

The recently developed modified damping capacity measuring instrument (Anycheck, Neobiotech Co., Ltd., Seoul, Korea) has high reproducibility, and it is possible to directly contact the measurement target by improving the hitting method [5]. The number of measurements was also reduced to six, and when the stability measurement was less than 70, the function of hitting the implant was decreased to two times to reduce the impact on the implant. There are several in vitro and animal tests, but there are still few studies on their effectiveness in clinical practice [5,6].

In this clinical study, the stability of implants during the healing period was verified using this new damping capacity assessment device. In addition, the similarity of the measured values was evaluated and compared with that of the existing Periotest M equipment.

2. Materials and Methods

Patients who visited the Korea University Anam Hospital from January 2020 to December 2021 and who had healing abutments placed after implant placement under local anesthesia were included in the study. The following patients were included in the study: those who planned to have a dental implant and healing abutment placed on the day of surgery and those who were older than 19 years who had a firm willingness to participate in this study and eventually agreed to participate in the study. Patients were excluded if the implant was replaced due to previous failure, placed immediately on the same day after tooth extraction, or if the procedure included a large amount of vertical augmentation of the alveolar bone or sinus grafting due to severe bone loss. A total of 38 patients with 50 implants were included in this study. This prospective clinical study was conducted with the approval of the Institutional Review Board of Korea University Anam Hospital (No. 2020AN0105).

Implant-first surgery was performed under block or infiltration anesthesia using 2% lidocaine epinephrine (1:100,000 epinephrine containment) in the outpatient clinic. If bone defects, such as dehiscence, existed, bone grafting using xenografts (BioOss, Geistlich Pharma AG, Zürich, Switzerland) was performed simultaneously with implant placement. Only bone level and internal hex connection fixtures (LUNA, Shinhung Co., Ltd., Seoul, South Korea; IS Ⅱ or IS Ⅲ, Neobiotech Co., Ltd., Seoul, Korea) were used for implant placement. The healing abutment was placed after implant placement, and if the incision was previously made, sutures were made using nylon without tension. Implant stability was measured as previously described. After pressure dressing with a sterile gauze bite was performed, postoperative caution was explained to the subjects. An antibiotic (cephalexin 1000 mg, t.i.d.) and a non-steroidal anti-inflammatory agent (zaltoprofen 80 mg, t.i.d.) were prescribed for 5 days, and 0.12% chlorhexidine solution mouth rinse was administered daily.

Implant stability was measured twice each on the buccal (labial) and lingual (palatal) sides using two different damping capacity analysis devices (Periotest M, Anycheck). The stability value measured by Periotest M is referred to as the Periotest value (PTV), ranging from −8.0 to +50.0, which is closer to −8.0% when the material has more rigidity. It was measured through 16 tapping motions. The value of the implant stability test (IST) measured by Anycheck was designed to be similar to the implant stability quotient value (ISQ scale), ranging from 0 to 100, and was measured through six rounds of slight tapping motion. The IST value was then calibrated according to the height of the healing abutment according to the manufacturer's instructions: no calibration at 4 mm height, +2 per 1 mm shorter, and −2 per 1 mm longer than the height of the healing abutment. When both devices are driven at a point 2–3 mm away from the healing abutment, the stability value is derived through effective hitting (Figure 1).

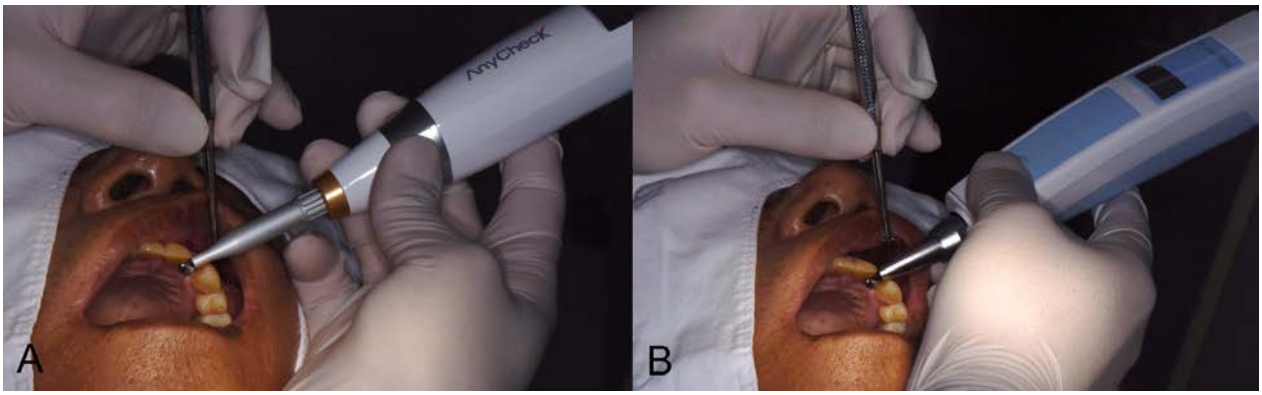

Figure 1. Clinical application of Anycheck and Periotest M equipment. (**A)** Anycheck, (**B)** Periotest M).

The participants were instructed to visit the clinics at 2 weeks, 1 month, 2 months, and 3 months after the first implant surgery. At each follow-up, stability measurements were performed in the same manner as on the operative day. After 3 months, the patients were referred to the prosthodontic department for implant prosthesis restoration, if no major complications occurred, or additional follow-ups were arranged if the stability value was considered insufficient to be loaded (Figure 2). In addition to implant stability, implant sites, type of fixtures, diameter and length of the fixtures, the gingival height of the healing abutments, and bone grafting were recorded at all follow-up periods.

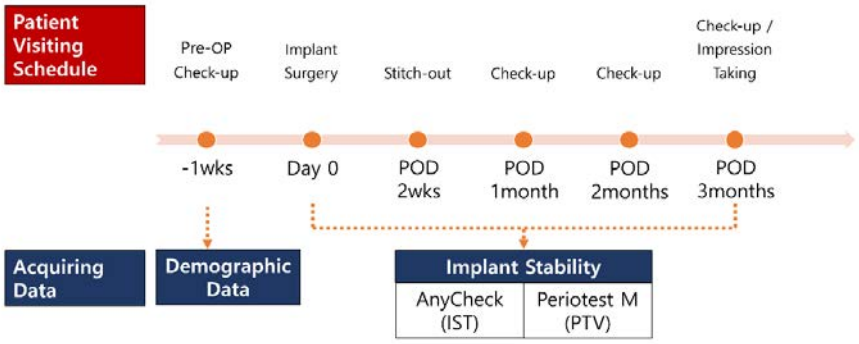

Figure 2. Schematic diagram of the clinical trials.

For statistical analysis, the implant stability measured by damping capacity analysis devices after implant placement was evaluated using covariance analysis of repeated measurements implemented using SAS Proc Mixed (SAS Institute, Inc., Cary, NC, USA). The device (Periotest M or Anycheck) was the between-subject factor and time (on the day of surgery, 2 weeks, 1 month, 2 months, 3 months) was the within-subject factor. MEAN/SD is the observed mean and standard deviation and LSMEAN/SE is the predicted mean and standard error of the statistical model. The scales of the two measurement devices were standardized using the Z-score standardization method. Statistical significance was set at $p < 0.05$. Analyses were performed for the buccal (labial) side, lingual (palatal) side, and total values. Statistical analysis was performed using the Statistical Analysis System version 9.4 (SAS Institute, Inc., Cary, NC, USA).

3. Results

The characteristics of the participants and the implants are presented in Table 1. The mean age was 66 years, and 20 men and 18 women were included in the study. Twenty-three implants were placed in the maxilla, 27 in the mandible, 4 in the anterior region, and 46 in the posterior region. Implant fixtures from the following three manufacturers were used: LUNA (Shinhung, Seoul, Korea), 22; ISII (Neobiotech, Seoul, Korea), 20; and ISIII (Neobiotech, Seoul, Korea), 8. For the fixture size, six short implants and 49 regular implants were used. For the height of the healing abutment, 4 mm was used the most (26 pieces). Bone grafting was performed on 21 patients.

Table 1. Demographic data of the patients and characteristics of the dental implants.

Investigated Item	Number
Patients	38
Age, mean (range)	66 (36–89)
Sex	
Male	20 (53%)
Female	18 (47%)
Total implants	50
Jaw	
Maxilla	23 (46%)
Mandible	27 (54%)
Location	
Anterior	4 (8%)
Posterior	46 (92%)
Fixture (manufacturer)	
LUNA (Shinhung)	22 (44%)
IS Ⅱ (Neobiotech)	20 (40%)
IS Ⅲ (Neobiotech)	8 (16%)
Fixture (size)	
Length	
Short (<8.0 mm)	6 (12%)
Regular (8.0–11.5 mm)	43 (86%)
Long (>11.5 mm)	1 (2%)
Diameter	
Narrow (≤3.5 mm)	1 (2%)
Regular (4.0–5.0 mm)	49 (98%)
Wide (>5.0 mm)	0
Healing abutment (GH)	
3 mm	4 (8%)
4 mm	26 (52%)
5 mm	12 (24%)
6 mm	7 (14%)
7 mm	1 (2%)
Bone grafting	21 (42%)

The mean values and standard deviations of measured stability at each follow-up period are presented in Table 2. When stability was measured using Periotest M, the average stability immediately after surgery decreased at two weeks but gradually increased thereafter, showing overall higher stability at the end of three months than immediately after surgery. In the case of Anycheck, similar to Periotest M, the average of the measured

values decreased in the second week after the operation, but gradually increased thereafter and showed higher stability than immediately after the operation from one month. (Table 2, Figure 3). This trend was similar for the buccal, lingual, and average scores. Contrary to the pattern of the measured values, both the standardized Z-scores of Periotest M and Anycheck showed a significant increase with time after a decrease at two weeks postoperatively (Table 3, Figure 4) ($p < 0.0001$). This is illustrated in Figure 4. This trend was significantly observed in the buccal, lingual, and average areas. It is observed that the "stability dip" is formed between two weeks and one month after implant placement, and the stability increases rapidly as it reaches the third month. At all time points, no difference in the standardized values was observed between the two instruments, Periotest M and Anycheck ($p > 0.01$).

Table 2. The mean value and standard deviation of measured stability at each follow-up period.

Device	Post-op Period	Mean	SD
Periotest M	Op	−4.72	2.92
	2 W	−4.25	4.37
	1 M	−4.62	3.50
	2 M	−4.57	3.34
	3 M	−5.29	2.84
Anycheck	Op	76.10	6.89
	2 W	75.82	9.87
	1 M	76.40	8.42
	2 M	76.50	7.85
	3 M	77.48	6.92

Abbreviation: Op, operation day; 2 W, post-operative 2 weeks; 1 M, post-operative 1 month; 2 M, post-operative 2 months; 3 M, post-operative 3 months.

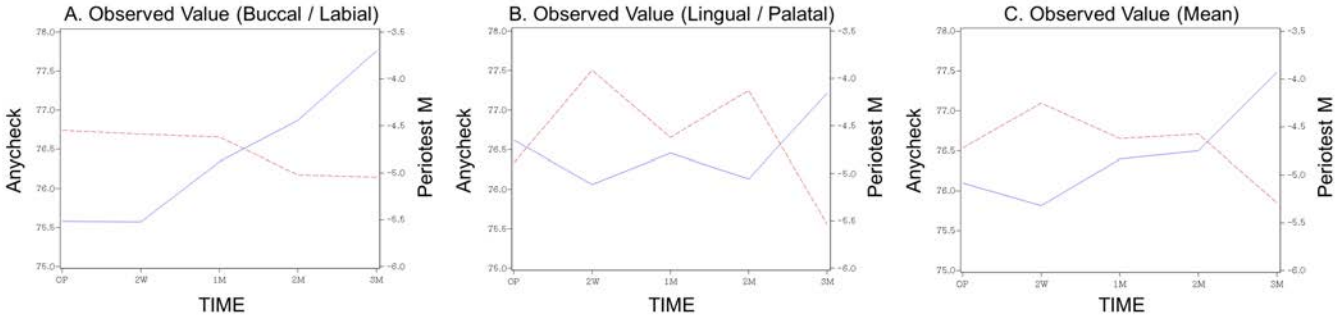

Figure 3. The observed values over time. (**A**) Buccal, (**B**) lingual, (**C**) mean.

Table 3. The implant stability measured by damping capacity analysis devices after implant placement.

	Tapping Location	Mean	SD	LSMEAN	SE	*p*-value
Periotest M	both	0.000	0.999	0.04322	0.07911	0.6626
Anycheck		0.000	0.999	−0.0030	0.07911	
OP		−0.014	0.861	−0.014	0.06071	
2 W		−0.090	1.219	−0.107	0.08685	
1 M		−0.005	1.025	−0.037	0.07259	<0.0001
2 M		0.005	0.942	0.028	0.07063	
3 M		0.157	0.837	0.231	0.06275	
Periotest M	Buccal	0.000	1.000	0.021	0.1192	0.9275
Anycheck		0.000	1.000	0.006	0.1192	
OP		−0.078	0.933	−0.078	0.09283	
2 W		−0.072	1.172	−0.096	0.1178	
1 M		−0.016	1.061	−0.058	0.1053	0.0325
2 M		0.086	0.875	0.099	0.08901	
3 M		0.148	0.861	0.201	0.09207	
Periotest M	Lingual	0.000	1.000	0.066	0.1058	0.5173
Anycheck		0.000	1.000	−0.024	0.1058	
OP		0.049	0.782	0.049	0.07777	
2 W		−0.108	1.270	−0.120	0.1278	
1 M		0.006	0.995	−0.012	0.0998	0.0031
2 M		−0.076	1.003	−0.050	0.1093	
3 M		0.165	0.819	0.238	0.08636	

Abbreviation: Op, operation day; 2 W, post-operative 2 weeks; 1 M, post-operative 1 month; 2 M, post-operative 2 months; 3 M, post-operative 3 months. Device (Periotest M or Anycheck) was the between-subject factor and time (OP, 2 W, 1 M, 2 M, 3 M) was the within-subject factor. MEAN/SD is the observed mean and standard deviation and LSMEAN/SE is the predicted mean and standard error of the statistical model. The scales of the two measurement devices were standardized using the Z-score standardization method. Statistical significance was set at $p < 0.05$.

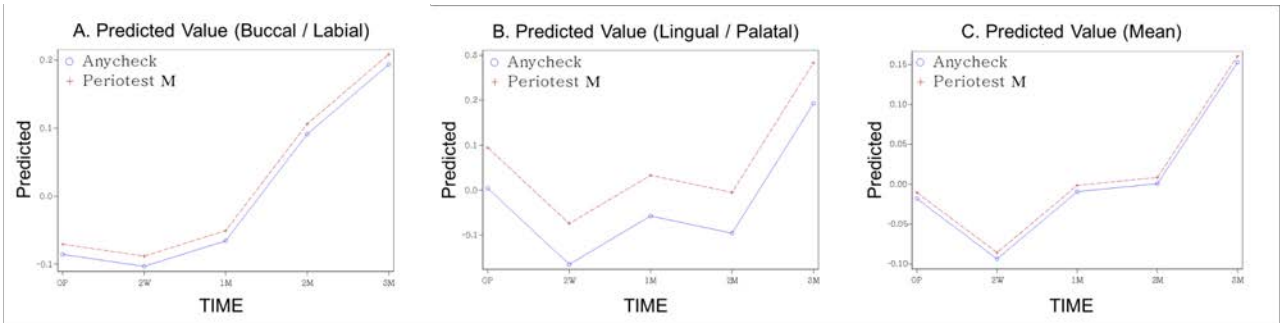

Figure 4. The predicted value over time (Z-score standardized, (**A**) buccal, (**B**) lingual, (**C**) mean).

4. Discussion

The results of this study showed that the damping capacity of Anycheck at all time points and in all hitting directions showed a tendency similar to that of Periotest M. Although the measured values were different, in the corrected values, the results of the two instruments were almost identical. In addition, after a slight decrease in stability two weeks after implant placement, implant stability increased over time, and both devices showed a significant difference with time.

Currently, the most widely used devices for measuring dental implant stability are Osstell, which can measure ISQ values based on resonance frequency analysis, and Periotest M, which is based on damping capacity assessment, as mentioned in the introduction [7]. The advantage of Osstell is that there is no tapping of the implant during measurement; therefore, there is less discomfort for the patient. However, for each implant product, a smart peg with a matching inner surface must be provided, and the smart peg fastening process may affect the fixation of implants with weak initial stability [8,9]. In the case of Periotest M, there is no such connection process, but the blow is strong and the number of blows is relatively large (16), which can cause patient discomfort, and the measured value can be affected by the blow angle [10,11].

The Anycheck device is an improved version of these two devices. It does not require a superstructure connection process such as Osstell for measurement, and the strength and frequency of blows have been dramatically improved compared with Periotest M [5]. In addition, to increase the user's intuition, it is displayed differently in red, orange, and green depending on the range of the measured value, in order that stability can be recognized without reading the number [5]. Therefore, the Anycheck device makes it easier to measure implant stability than existing devices. However, despite having a wider effective striking angle than Periotest M, it can only be measured when the striking angle is in the range of 0° to 30° from the ground, and the final result value must be corrected because the resulting value may vary depending on the length of the healing abutment [6].

Implant stability is divided into two types: primary and secondary. Primary stability refers to the initial mechanical stability, which occurs because of friction through contact between the bone and implant surface [12]. If the initial fixation is insufficient and the micro-movement reaches a level exceeding 50–100 μm, osseointegration may be damaged, and as a result, tissues other than bone, such as fibrous tissue, may be formed around the implant [13]. Secondary stability refers to the stability of the biological form through bone regeneration and remodeling at the implant-tissue interface [14]. Differentiating osteogenic cells migrate to the implant surface to form a mineralized interfacial matrix around the implant and then undergo remodeling to complete osseointegration [15]. Total implant stability is composed of synthesizing this primary and secondary stability, and most of the studies on total implant stability report that the value decreased slightly immediately after implant placement and then gradually increased thereafter [16–18]. This pattern has been described as a drop or dip [19]. In one study, it was mentioned that this dip exists between two and four weeks using a mathematical model through curve-fitting [20], and a similar pattern of stability change was also observed in this study. At the second week after the operation, the measured values of both devices showed a decreasing pattern and then gradually increased thereafter. This means that the theoretical stability dip is also observed in actual clinical practice. Furthermore, this suggests the need to easily and conveniently measure implant stability in order that implants can be loaded at the right timing.

There are many studies on the comparison of Osstell, and Periotest M, which are existing devices for measuring implant stability, and the clinical similarity between the two devices has been verified to some extent [3,6,21–26]. The Anycheck device was developed relatively recently; therefore, there are not many studies using the Anycheck device. In particular, no clinical studies have yet been conducted. However, a high similarity between Anycheck and other devices can be observed consistently in existing studies and in this clinical study. In a validity analysis of an ex vivo study using porcine bones, a very high correlation was observed between the measured values of Anycheck, Osstell, and Periotest M, and a linear relationship between the insertion torque and the measured values was observed [6]. Similarly, in one in vitro study, a high correlation between the three devices was observed, and it was observed that the diameter of the healing abutment did not affect the measured value, unlike the healing abutment length, which affected the Anycheck measured value [5]. A previous study observed a linear correlation between the

vibration frequency and the Anycheck value measured while controlling the peri-implant artificial bone level [27].

This clinical study has some limitations. Although Osstell and Periotest M showed almost equal reliability in numerous studies, Osstell was not applied in this study. However, if comparison with Osstell were performed, abundant results would have been derived. In addition, the fact that the effects of the jaw arch, implant specifications, and bone graft could not be controlled is another limitation of this study. Nevertheless, in the results, a similar and uniform tendency of the Anycheck device could be observed when compared with Periotest M, and the similarity along the timeline could also be observed; therefore, it is considered that the clinical significance of this study is sufficient. Through this prospective clinical study, the new damping assessment device with reduced patient discomfort and high clinical versatility suggested the possibility of clinical replacement by showing implant stability measurements similar to those of existing equipment.

5. Conclusions

During the observation period of three months, the damping capacity of Anycheck showed a similar tendency to that of Periotest M. After a slight decrease in stability two weeks after implant placement, implant stability increased over time. Through this study, the clinical substitution potential of the Anycheck device, which has a simpler measurement method and equivalent implant stability measurement power, was observed.

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