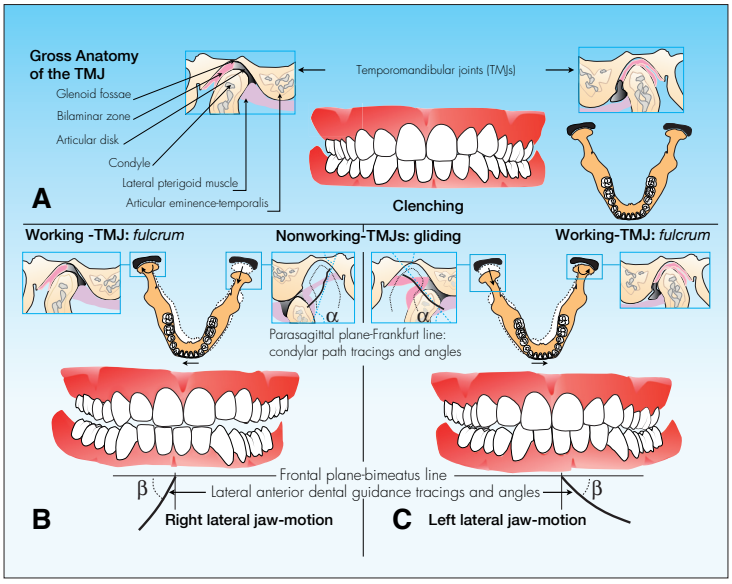
Tesis Doctoral

# THE HABITUAL CHEWING SIDE SYNDROME

Urbano A. Santana Mora




Departamento de estomatología
Facultad de Medicina y Odontología

Santiago de Compostela

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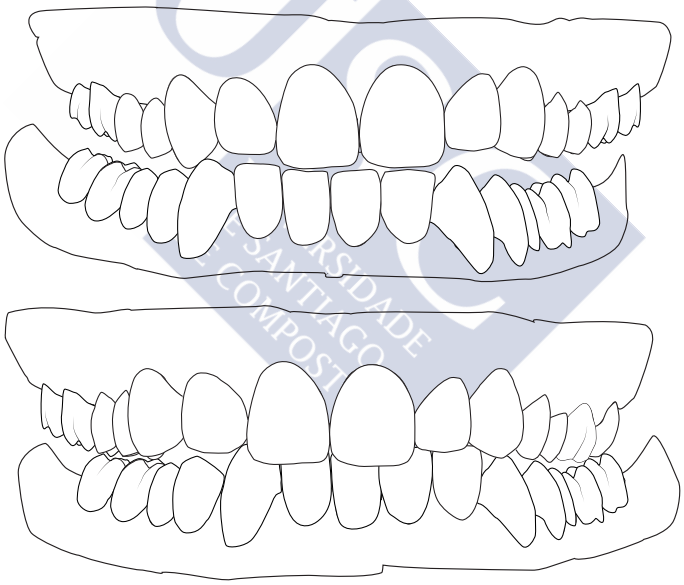

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Prof. Dr. D. Arturo Martínez Insua, Prof. Dr. D. José Luís López-Cedrún Cembranos, Prof.

Dr. D. Jean-Louis Raymond , como Directores de la tesis titulada:

"The habitual chewing side syndrome"

Por la presente **DECLARAMOS:**

Que la tesis presentada por Don Urbano Alejandro Santana Mora

es idónea para ser presentada, de acuerdo con el artículo 41 del "*Regulamento de Estudos de Doutoramento"*, por la modalidad de compendio de ARTÍCULOS, en los que el doctorando tuvo participación en el peso de la investigación y su contribución fue decisiva para llevar a cabo este trabajo.

Y que está en conocimiento de los coautores, tanto doctores como no doctores, participantes en los artículos, que ninguno de los trabajos reunidos en esta tesis serán presentados por ninguno de ellos en otra tesis Doctoral, lo que firmamos bajo nuestra responsabilidad.

Santiago de Compostela, a 15 de Diciembre de 2014

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Y, permítanme la licencia, es de justicia reconocer la dedicación del Profesor Santana-Penín, sin cuyo apoyo este trabajo quizá no hubiese visto la luz. *Muchísimas gracias papá*

*A mis padres y a mi esposa.*

*Por que sin su apoyo e infinita paciencia,*
*este trabajo no habría sido posible*

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# Resumen

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# Resumen

La articulación entre los huesos temporales y la mandíbula recibe el nombre de articulación temporomandibular (ATM); es una articulación bilateral, ginglimoide diartrodial, de rotación y traslación, que dispone de un disco intraarticular. El movimiento del compartimento superior es principalmente de traslación, mientras que el inferior es principalmente de rotación. El síndrome de dolor-disfunción o trastorno o desorden de la ATM (TTM) es un término colectivo que engloba una serie de problemas clínicos de los músculos de la masticación, la articulación temporomandibular (ATM) y las estructuras adyacentes; constituye un subgrupo de trastornos musculoesqueléticos y se han identificado como una causa importante de dolor orofacial de origen no dental.

El sitio web del "*National Institute of Craniofacial Research*" (NIDCR) informa que la prevalencia de TTM sólo es superada por el dolor lumbar entre los trastornos musculo-esqueléticos incapacitantes. Afecta aproximadamente a entre el 5 y el 12% de la población, con un coste directo anual estimado de 4 mil millones de dólares, en EEUU. Aproximadamente, de la mitad a dos tercios de las personas con trastornos de la ATM buscará tratamiento. Los investigadores han encontrado que el 28% de los pacientes con TTM informaron tener un mayor número de discapacidades y limitaciones, además de encontrarse desocupados; por otra parte, emplearon más todo tipo de servicios de salud y supusieron un mayor coste.

Los TTM son considerados como una enfermedad crónica y, a excepción de la etiología traumática, se desconoce su causa. La mayoría de las personas no presentan ningún síntoma aun teniendo imágenes de resonancia magnética positivos para TTM, con una prevalencia similar en ambos sexos; sin embargo, la necesidad de tratamiento para los TTM en adultos se estimó en un 15,6%, y fue significativamente mayor en mujeres que en hombres.

La clínica de los TTM es típicamente fluctuante. Aproximadamente el 90% de los pacientes con dolor por TTM se puede tratar utilizando el asesoramiento y/u otros tratamientos conservadores. Sin embargo, se ha comunicado que no hay diferencia entre las terapias conservadoras (fármacos, férulas, etc.) frente a los grupos de control (ningún tratamiento).

Actualmente el diagnóstico de los TTM se basa en la anamnesis y en la exploración clínica. El diagnóstico diferencial con otros dolores faciales es importante y puede requerir de interconsulta, en ocasiones de urgencia (como cuando existen síntomas de los pares craneales), con otros especialistas. En el momento actual, probablemente el criterio más empleado es el DC/TMD, adoptado por las principales asociaciones de dolor facial, como la Asociación Americana para el Dolor Orofacial (AAOP). La clasificación DC/TMD diferencia entre TTM articulares y musculares; ambos pueden cursar con o sin desórdenes internos de la ATM; en esta clasificación se ha incorporado el dolor de cabeza secundario a los TTM.

Aunque se ha sugerido que el aparataje electrónico no resulta de utilidad en el diagnóstico de esta patología, se han empleado diversos dispositivos en multitud de investigaciones, y en la USC se emplean de modo rutinario para realizar el diagnóstico y plan terapéutico de los pacientes en la actividad clínica, como se describe a continuación.

La *kinesiografía* (*gnatografía* en nuestro campo) ha permitido cuantificar diversos parámetros, como la magnitud de los movimientos mandibulares

y determinar el valor de los ángulos que conforman respecto a planos convencionales. La gnatografía digital permite además determinar la velocidad del desplazamiento de un punto incisal concreto; aunque el significado de los registros no ha mostrado especificidad ni tampoco sensibilidad diagnóstica específica, un estudio mostró correlación entre la inclinación de la guía dentaria anterior con los TTM, indicando que en el lado más horizontal, la mandíbula se desplazaba ipsilateralmente durante la apertura máxima, lo que sugiere un TTM ipsilateral. Nuestras investigaciones apoyan este hallazgo.

La *axiografía* ha permitido registrar en forma gráfica, cuantificable y objetiva, el movimiento condilar; existe controversia sobre la interpretación de esta variable en los diferentes estudios. La mayoría de los autores coincide en admitir que la trayectoria condilea (TC) es más elevada en los sujetos con TTM (debido a la remodelación de la eminencia temporal), aunque otros autores han sugerido lo contrario (debido a la artrosis).

El estudio mediante electromigrafía (EMG) de superficie (*s*EMG) de los músculos elevadores ha sido útil en estudios de fisiología básica aplicada; permite registrar la intensidad y duración de la actividad muscular. No obstante, no se ha demostrado su utilidad clínica debido a su relativamente baja reproducibilidad y a la cantidad de tiempo que requiere cada estudio. El empleo de datos normalizados, parece haber introducido un nuevo enfoque con un mejor rendimiento de esta exploración. La sEMG puede ser complementada con el empleo simultáneo de células de carga, permitiendo registrar en tiempo real las fuerzas oclusales efectivas ejercidas.

Este estudio se centró en la valoración de la función masticatoria de sujetos sanos y pacientes con TTM. Este aspecto ha sido valorado de modo minucioso en nuestras observaciones, empleando varios test clínicos y entrevista personal, intentando poner de manifiesto la preferencia masticatoria observada no solo en el momento de las exploraciones sino también la posibilidad de haber realizado algún cambio en el lado de masticación.

La masticación por un lado concreto (lateralidad masticatoria) es más frecuente en pacientes con TTM que en sujetos sanos, no obstante no se había establecido cual era el lado habitual de masticación en pacientes con TTM unilaterales, la patología más común. Aunque no es raro observar síntomas bilaterales, es razonable asumir que alguna de estas observaciones puede instaurarse de modo bilateral, aunque la experiencia demuestra que en ocasiones comienza por un determinado lado y durante la progresión de la enfermedad puede instaurarse en el lado inicialmente no afectado; incluso puede haber cambiado el lado afectado de un momento a otro; desde un punto de vista sintomático, la naturaleza de esta enfermedad es fluctuante.

La posible influencia de la función masticatoria en la remodelación de las ATMs, la inclinación de las TCs y de las guías laterales, ya observadas aisladamente por otros autores, se ha valorado en conjunto en este estudio. Se planteó la hipótesis nula de no asociación entre estas variables: lado con TTM, lado de masticación y factores oclusales periféricos (pendiente condilar y guía lateral anterior).

Ya que la función masticatoria necesita una actividad muscular específica, parece lógico valorar la co-activación muscular; su complejidad ha requerido valorar aspectos básicos antes que los puramente funcionales, como son: la reproducibilidad de la metodología y los valores de tareas básicas en sujetos sanos y enfermos. Se plantearon las hipótesis nulas de no diferencias entre ambos lados en pacientes con TTM unilateral, así como no diferencias entre sanos y enfermos.

Hemos valorado simultáneamente la co-activación muscular y la actividad electromiográfica de los principales músculos elevadores de la mandíbula: maseteros y temporales, durante el esfuerzo isométrico y el apretamiento incisal mediante célula de carga durante el cierre simétrico mandibular. Se valoró la hipótesis nula de no diferencias de la actividad muscular de los cuatro músculos elevadores en sujetos libres de sintomatología, de similares edades y estado dental.

Aunque también se han empleado test psicológicos que pretenden valorar la repercusión de esta patología en la calidad de vida, éstos no serán expuestos extensamente en este trabajo de investigación.

El desarrollo de este estudio, en cuanto a metodología, resultados y su interpretación, comprende los tres capítulos siguientes:

I. **La función masticatoria alterada y su significado clínico: El síndrome del lado habitual de masticación.**

II. **La actividad EMG de los músculos masticatorios.**

III. **La correlación entre la sEMG de los músculos masticatorios y las cargas efectivas incisales.**

# MÉTODO

## I. La función masticatoria alterada y su significado clínico: El síndrome del lado habitual de masticación.

Con la finalidad de llevar a cabo un ensayo clínico aleatorizado ("Occlusal Adjustment as Treatment for Chronic Orofacial Pain"; ClinicalTrials.gov Identifier: NCT00899717) se realizó el diagnóstico clínico de pacientes con TTM crónico. Intentó obtenerse una muestra homogénea en cuanto al factor principal, el dental, como agente mayor de la función masticatoria. Los pacientes debían tener TTM crónico y dentición natural completa en normo-oclusión, excluyendo aquellos casos en los que un ajuste oclusal mínimamente invasivo no permitiese equilibrar la oclusión. Se evaluaron: las TC mediante axiografía convencional (Kit Reqistier Ausrustunq "C"; Condylator service, Zurich, Switzerland), los ángulos de las guías de lateralidad mandibular mediante gantografía (K6I/CMS, Myotronics Normed Inc, Seattle, Wash.), y la función masticatoria mediante observación directa.

Las comparaciones se realizaron de forma independiente. Para las variables categóricas se utilizó la prueba de chi-cuadrado ($\chi^2$) y, *post-hoc*, la prueba exacta de Fischer. Las variables continuas se compararon mediante la prueba t de Student. Las variables continuas con tres o más brazos se evaluaron mediante análisis de la de varianza de medidas repetidas (ANOVA). El nivel alfa se fijó en $p = 0,05$ y la repetibilidad de las medidas fue determinada mediante test de concordancia (ordinales) o mediante el coeficiente de correlación intraclase (continuas).

**II. La actividad EMG de los músculos masticatorios.**

Se realizaron registros *s*EMG de sujetos sanos y pacientes con TTM. Se evaluaron 93 pacientes en un estudio y 50 en otro (25 pacientes con TTM derecha, 25 pacientes con TTM izda; además de éstos, otros 25 sujetos sanos fueron evaluados como grupo control de comparación). Para el diagnóstico de los TTM se empleó el test RDC/TMD y el índice de Helkimo. El método para el registro electromiográfico fue descrito en el artículo publicado en el año 2009. Para realizar comparaciones entre las variables de *s*EMG se emplearon el modelo lineal mixto, modelo GMA (*Generalized Additive Models*) y el índice de Youden, por estadísticos académicos independientes. En otros casos, para comparar variables no paramétricas, se emplearon los diferentes tests no paramétricos, dependiendo del número de grupos, variables y del análisis intra- o inter-grupos / individuos.

**III. La correlación entre la sEMG de los músculos masticatorios y las cargas efectivas incisales.**

Este estudio trata de estimar la carga en la ATM durante el apretamiento incisal utilizando un dispositivo de célula de carga a medida y relacionarlo con la actividad electromiográfica registrada mediante sEMG, obteniendo registros conjuntos que permitieron evaluar la correlación de los resultados.

Las fuerzas interincisales fueron registradas mediante un dispositivo que consistió en un alicate estándar (21.380-200CHR, V. Herramientas

Eurotools SA, Vitoria, España) con inserciones de plástico (diámetro de 6 mm; 003-349-00 + 045-005-00; Dentaurum, Ispringen, Alemania) fijadas en los brazos activos para eliminar la rigidez del material metálico, en los que se practicaron surcos cómodos para los bordes incisales. Una mini célula de carga (Skalierdaten, Tipo 9205-V001, hasta 203,88 Kg o 2 kN; Praezisionsmesstechnik GmbH & Co. KG, Gernsbach, DE) con un rango de salida nominal de 0 a 3 mV / V, una impedancia de entrada de 200 GΩ y una precisión de ≤.05%, se colocó en los brazos posteriores de los alicates, que fueron reforzados para reducir su flexión. La célula de carga se conecta mediante un puerto USB a un PC compatible, equipado con un procesador Intel Core (CPU i5-2430M; 2,40 GHz), sistema operativo Windows 7 Professional (Microsoft Corp., Redmond, WA, EE.UU.) y DIGIVISION, software de la célula. La célula de carga fue previamente calibrada en una máquina universal de ensayos (Instron 4400; Instron Corp., Norwood, MA, EE.UU.), que mostró una correlación lineal entre las fuerzas aplicadas y registradas, siguiendo el coeficiente de transformación y=2,0833 . Los datos de la celda de carga se multiplicaron por la constante para obtener las verdaderas cargas en Newtons (N). Se hizo un esfuerzo para construir un dispositivo de un material seguro (virtualmente indestructible) con el fin de reducir en lo posible el grado de apertura de la boca durante el registro.

Evaluamos 23 sujetos voluntarios sanos. La carga incisal submáxima y media fueron registradas empleando la célula de carga electrónica calibrada; simultáneamente, se registró la actividad electromiográfica de la los maseteros y músculos temporales mediante sEMG.

Se tomaron registros de reposo, apretamiento incisal submáximo y medio (50%). Previamente se ensayó cada tarea con cada participante (*bio-feedback*). La célula de carga se colocó paralela al plano oclusal, registrando la fuerza después de que la mandíbula avanzase hasta lograr una relación incisal de borde a borde. La magnitud de este desplazamiento anterior dependía del resalte incisal, y varió de 1,5 a 3 mm en esta muestra (medido mediante un pie de rey). La actividad EMG recogida durante el apretamiento submáximo voluntario

se utilizó como una referencia para la normalización. Los participantes observaron en la pantalla en tiempo real, el registro gráfico resultante de las fuerzas aplicadas que muestran la magnitud de la fuerza. Luego se les instruyó para que aplicasen una fuerza submáxima y a continuación la redujesen hasta el 50% de la submáxima que veían en pantalla.

Se emplearon diferentes tests según las características de las variables y comparaciones. (test *t*, ANOVA, Friedman, Kruskal-Wallis, *U* de Mann-Whitney, *o* Wilcoxon); la reproducibilidad de las variables se valoró mediante el test de correlación intraclase.

# RESULTADOS

## I. La función masticatoria alterada y su significado clínico: El síndrome del lado habitual de masticación.

Dieciséis de los 20 participantes con síntomas unilaterales masticaban por el lado afectado; la concordancia (prueba exacta de Fisher, $p$ = 0,003) y el nivel de concordancia-simetría (Kappa coeficiente $\varkappa$ = 0,689; 95% intervalo de confianza [IC], 0,38-0,99; $p$ = 0,002) fueron significativos. El ángulo medio de la TC fue más elevada (53,47 (10,88) grados frente a 46,16 (7,25) grados; $p$ = 0,001), y el ángulo medio de la guía lateral anterior era más plano (41,63 (13,35) grados frente a 48,32 (9,53), $p$ = .036) en el lado sintomático. *Poder de este estudio*. Con un tamaño muestral de 19 pacientes, y suponiendo una prueba de dos colas en el nivel alfa de 0,05, el estudio tuvo un poder de 0,8 para detectar un valor de Kappa de 0,6 o mayor al probar la hipótesis nula Kappa = 0.

## II. La actividad EMG de los músculos masticatorios.

Los pacientes con TTM unilateral mostraron un aumento de la actividad del músculo temporal contralateral y una disminución, ambas significativas, de la actividad del masetero ipsilateral.

Por otra parte, los pacientes con TTM mostraron diferente co-activación muscular que los sujetos sanos, lo que permitió clasificar entre el 60 y el 70 % de los sujetos mediante sEMG. El músculo temporal anterior, en concreto el izquierdo en nuestra muestra de sujetos con preferencia manual derecha, permitió demostrar asimetría intraindividuo, con mayores valores de este músculo en el lado derecho cuando la TTM es izquierda y viceversa.

La activación EMG se mostró más baja en los pacientes con TTM que en los sujetos control (temporal: 195,74 ± 18,57 µV vs 275,74 ± 22,11 µV, P = 0,011; maseteros: 151,09 ± 17,37 µV vs 283,29 ± 31,87 µV; P <0,001).

Se calculó un índice de asimetría para determinar las relaciones de derecha a izquierda activación unilateral. Los pacientes con TTM derecho unilateral mostraron un uso preferente de sus músculos del lado izquierdo y viceversa (-5.35 ± 4.02 y 6.95 ± 2.82, respectivamente; P = 0,016). Este índice permite diferenciar el lado afectado en la mayoría de los pacientes.

Durante el esfuerzo submáximo, los maseteros son las músculos más activos, ello permite inferir la distribución de cargas sobre ambas ATMs; no obstante, durante el esfuerzo de media intensidad, los cuatro músculos parecen actuar de modo equilibrado, lo que debería minimizar las cargas en las ATMs, explicando el potencial lesivo de fuerzas incisales excesivas o mantenidas sobre las ATMs.

*Capacidad de discriminación entre sujetos sanos y pacientes con TTM crónica de la sEMG*

De todas las variables estudiadas, los cuatro músculos y los diferentes índices de asimetría, (Activad y Torque), las que mejor capacidad discriminatoria mostraron fueron el músculo temporal anterior izquierdo en reposo (rLT) y cTORQUE ([(RT+LM)-(LT+RM)] / (RT+LM+LT+RM)), durante el máximo esfuerzo voluntario en máxima intercuspidación. La AUC alcanzó un valor de 0.742 (95% CI 0.783-0.934).

Con respecto a los estudios electromiográficos la revista *Pain Medicine* ha publicado una carta en la que se hicieron sugerencias para mejorar el diagnóstico de los TTM, basándonos principalmente en la posibilidad de minimizar el error tipo II o beta al optar por la hipótesis de no diferencia, y la conveniencia de realizar valoración de la función masticatoria obviada por otros autores.

**III. La correlación entre la sEMG de los músculos masticatorios y las cargas efectivas incisales.**

*Carga incisal*: La fuerza media registrada en sujetos adultos jóvenes sanos durante la mordida incisal submáxima voluntaria fue de 498 (305.78) N, y su magnitud se redujo a 268,93 (147,37) N cuando alcanzó el 50% de la carga submáxima incisal.

Durante el apretamiento incisal, la activación muscular parece ser dependiente de la intensidad de las fuerzas efectivas ejercidas. Las fuerzas de media intensidad (50% de la fuerza submáxima) son generadas por una actividad muscular equilibrada de los músculos elevadores explorados. Debido a que los músculos temporales contribuyen de modo similar a los maseteros, no deberían esperarse fuerzas excesivas, ya que las cargas en las ATMs parecen ser provocadas por los maseteros.

*Actividad EMG durante la mordida incisal submáxima voluntaria*: La actividad sEMG media normalizada de los cuatro músculos fue 49,99 (54,54)% µV. Hubo diferencias significativas entre los cuatro músculos ($p$ = 0,011). La media del par masetero fue 61,42 (35,63) µV y la del temporal fue 38,33 (21,61) µV ($p$ = 0,003; test de Wilcoxon).

*Actividad EMG durante la mordida incisal media (50% de la submáxima) voluntaria*: El valor medio normalizado de la actividad sEMG de los cuatro músculos fue 27,17 (15,29) µV%. No hubo diferencias significativas entre los cuatro músculos durante esta tarea (test con muestras relacionadas de dos colas de Friedman ANOVA por rangos, $p$ = 0,432).

*Cargas incisales submáximas versus medias y actividad sEMG normalizada*. No hubo asociación lineal de las variables sEMG y fuerza media incisal submáxima. La sEMG de los músculos maseteros indicó una correlación lineal con la magnitud de las fuerzas generadas incisales de intensidad media (coeficiente de correlación de Spearman = 0,639, $p$ <0,001). La actividad muscular aumentó de mordida incisal media a mordida incisal submáxima. Sin embargo, las contribuciones respectivas de los cuatro músculos fueron diferentes. El índice de asimetría (diferencias entre maseteros y temporales dividido por sus sumas) durante la carga incisal media fue de 18,02 (29,59) y durante el apretamiento submáximo fue 24,78 (26,19) (valores sEMG normalizados; las diferencias de medias = -6,76 (15,15), IC del 95%, -13,32 a -0,21, p = 0,044; t-test pareado). Por lo tanto, la contribución de los músculos maseteros fue más significativa que la de los músculos temporales en la realización de submáxima que la media fuerza incisal.

# DISCUSIÓN

Este es el primer estudio que muestra que los trastornos temporomandibulares unilaterales crónicos afectan principalmente el lado de masticación habitual, que además es el lado con una mayor trayectoria condílea y menor guía lateral anterior; esto permite proponer una nueva denominación, plausiblemente etiológica, del, hasta ahora denominado en base a los síntomas que presentaba el paciente, síndrome de dolor-disfunción de la ATM: el síndrome de lado habitual de masticación (HCSS).

Este estudio demuestra un comportamiento muscular específico en pacientes que sufren síntomas por presentar un lado habitual de masticación, sugiere la posibilidad de emplear sEMG para discriminar pacientes con HCSS y sanos, y demuestra la complejidad de la co-activación muscular durante la mordida incisal dependiendo de la magnitud de las fuerzas incisales efectivas.

## I. La función masticatoria alterada y su significado clínico: El síndrome del lado habitual de masticación.

Desde que Costen describiera en 1934 el síndrome de colapso de mordida, atribuyendo a la patología oclusal el origen de la patología dolorosa, se esta debatiendo la causa, aunque permanece sin establecer, constituyendo una entidad crónica sin tratamiento predecible. Nuestro estudio demuestra una asociación estadística entre síntomas, función masticatoria alterada, remodelación de la ATM y alteración de las guías laterales anteriores. No obstante, esto solamente sugiere la posibilidad de que sean factores contribuyentes, no demuestra científicamente la etiología. No obstante, debido a que en Biomedicina la relación causa-efecto se establece por la probabilidad (aunque no la seguridad) de que un factor provoque un evento, esta relación debe considerarse como factores con posibilidad de que sean etiológicos. Estudios futuros podrían esclarecer si esta asociación, además, es causal.

Este estudio de diagnóstico, difiere esencialmente del procedimiento usual de diagnóstico, que se basa en la exploración clínica, dinámica y palpación muscular, a la vez que en la descripción de los desórdenes internos. A diferencia de estos procedimientos, el nuestro incluye la valoración de las TC, de las guías anteriores y de la función masticatoria. Basándonos en estos criterios, hemos llevado a cabo un ensayo clínico aleatorio-placebo con 21 pacientes, en los que se demostró la eficacia de una terapéutica planificada para recuperar el cierre fisiológico mandibular y una función masticatoria alternante; los resultados principales fueron publicados en la base de datos internacional clinicaltrials.gov. En este momento se prosigue el estudio para valorar una población más extensa.

Se hizo un esfuerzo máximo para evitar sesgos de valoración y de determinación de las variables, realizando éstas diferentes autores en diferentes momentos, así como en las instrucciones dadas a los pacientes para la mayor precisión de los registros gráficos.

La variable principal, intensidad del dolor, fue autoadministrada y las demás fueron valoradas por investigadores diferentes del clínico-terapeuta; por ello, el estudio debe considerarse ciego simple con valoración independiente, alcanzando el significado del doble ciego.

**II. La actividad EMG de los músculos masticatorios.**

El hecho de que la mayoría de los HCSS sean unilaterales, argumenta en contra de la etiología general (Axis II, DC/TMD), incluyendo factores psicobiológicos, hormonales, genéticos y/o psicológicos. Por ello nos ha preocupado estudiar el HCSS como una patología que afecta en particular a determinados individuos, pero sobre todo el hecho de que afecte selectivamente solamente a uno de los lados; en consecuencia, mediante sEMG hemos valorado el comportamiento neuromuscular en sujetos con HCSS unilateral. Esta exploración demostró que el músculo masetero del lado afectado presenta una actividad reducida con respecto al lado de no trabajo, asintomático, siendo este masetero el que realiza el cierre mandibular de modo predominante; contrariamente, el temporal anterior mostró una mayor activación en el lado no sintomático, lo que, indirectamente permite suponer que el paciente tiende a colocar la mandíbula hacia el lado de no trabajo y no afectado, quizá para evitar presión en la zona retrodiscal de la ATM afectada. Esta reducción unilateral de la actividad de los músculos temporal y masetero podía ser considerada como una adaptación funcional de protección específica del sistema neuromuscular debido a estímulos aferentes nociceptivos.

El índice de asimetría (SAI, diferencias entre lados dividido por su suma) parece ser una medida útil para discriminar pacientes con frente a la derecha.

El estudio de las curvas ROC mostró cierta capacidad discriminatoria entre sanos y pacientes con HCSS. Quizá esta característica pueda indicar un comportamiento patológico de la musculatura en sujetos que podría sugerir fases preclínicas de la patología, pudiendo actuar precozmente,

antes de que se instaurasen lesiones irreversibles; este aspecto merece futuras investigaciones.

**III. La correlación entre la sEMG de los músculos masticatorios y las cargas efectivas incisales.**

Este estudio muestra que morder con los incisivos es una tarea compleja durante la cual, las intensidades de las fuerzas determinan la co-activación muscular. Este estudio indica una correlación positiva significativa entre las cargas efectivas incisales y la magnitud de la actividad de los músculos maseteros sEMG durante el apretamiento medio, pero no durante el submáximo. Por otra parte, mientras que durante el esfuerzo medio, masetero y temporal están activados, durante el esfuerzo submáximo se registró un predominio significativo del par masetero; basado en las predicciones del modelo, este estudio sugiere que el sistema estomatognático ajusta las fuerzas intentando minimizar las cargas en la ATM durante la mordida incisal media, pero no durante la submáxima-simétrica.

Estudios como el de Tanaka de 1994 incluyen un comportamiento biomecánico del aparato masticatorio único, asumiendo que la mordida incisal depende de la sección de los músculos elevadores, maseteros, pterigoideos internos y temporales. No obstante, nuestro estudio pone de manifiesto que esta relación única puede no ser la real, ya que la co-activación muscular depende de la intensidad de la fuerza, siendo equilibrada la actividad de los elevadores en fuerzas de intensidad media, pero sin embargo, para realizar fuerzas de intensidad submáxima, los músculos maseteros presentaron un predominio significativo. Esto sugiere que el aparato masticatorio se organiza para obtener fuerzas efectivas, aunque ello pueda significar aumentar las cargas en la ATM; por ello, pueden inferirse daños articulares si las tareas requieren un esfuerzo incisal sub/máximo o mantenido, explicando así la conveniencia de evitar éstas.

En suma, (1), el diagnóstico de los trastornos temporomandibulares probablemente debería incluir una valoración de la función masticatoria,

la cualidad del cierre y de las lateralidades mandibulares. (2), El estudio mediante sEMG mostró una capacidad diagnóstica moderada. Por último (3), el apretamiento incisal debe ser considerado como una tarea compleja y dependiente de la magnitud de las fuerzas efectivas ejercidas.

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# Acronym's list

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# Acronym's list

Ai: asymmetry index

AUC: area under the ROC curve

CAEI: Comité Autonómico de Ética de la Investigación de Galicia

CP: condylar path

HCC: habitual chewing side

HCSS: habitual chewing side syndrome

ICC: Intraclass correlation coefficient

IRB: Institucional Review Board

LG: lateral anterior dental guidance

LM: left masseter

LT: left temporalis

RM: right masseter

ROC: receiving operating curve

RT: right temporalis

TMJ: temporomandibular joint

TMD: temporomandibular disorders

TORQUE: torque index

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# Introduction

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# Introduction

The World Health Organization (WHO) website considers two types of diseases: acute and chronic; acute diseases for those who have a clearly defined beginning and end, and are of short duration; chronic diseases are those of long duration (usually more than 6 months) and generally of slow progression. Usually, chronic diseases are often of unknown cause, so their treatment can be palliative or symptomatic, but not causal neither predictable. The Temporomandibular disorders (TMD) represent the most common chronic orofacial pain condition.

The prevalence of treatment need for temporomandibular disorders in adults was estimated to be 15.6% (Al-Jundi *et al.*, 2008), being significantly higher in females than in males (Sessle, $2000_b$; Nilsson *et al.*, 2009). The *NIDCR* website states that TMDs are second only to low back pain among disabling musculoskeletal conditions; affecting approximately 5 to 12% of the population, with an annual direct cost estimated at $4 billion (in US). About half to two-thirds of those with TMJ disorders will seek treatment.

*Temporomandibular joint (TMJ) disorders (TMD)* are defined as a subgroup of craniofacial pain problems that involve the masticatory musculature, the temporomandibular joints (TMJs), and associated structures (De Leeuw, 2008). Pain and/or limited mouth opening are the main symptoms. The terms "Temporomandibular disorders", "TMJ disfunction syndrome", "myophascial pain" or "Costen syndrome" (collapsed bite), usually refer to the description of symptoms or affected areas.

Except for the traumatic etiology, the cause of temporomandibular disorders remains unknown (Clark, 1991; Brooks *et al.*, 1997; Hylander, 2006; Scrivani *et al.*, 2008; De Leeuw , Klasser, 2013); it is considered multifactorial, including physical-peripheral and psychosocial-central factors (Suvinen *et al.*, 2007; Diatchenko *et al.*, 2005; Tanaka *et al.*, 2008). The suggested main involved etiologic factor of temporomandibular disorders is the TMJ overloading, collapsing joint lubrication and generating free radicals and hypoxia when it exceeds the capillary perfusion pressure (Nitzan, 2001; Tanaka *et al.*, 2008). The suggested oclusal factors contributors have been studied, including mainly occlusal disharmonies; but no studies included the impaired masticatory function nor dynamic jaw-lateral horizontality factor.

The TMJ is a ginglimo-di-arthrodial joint designed to perform rotational movements (mainly on the working side) and displacement (mainly on the nonworking side); an avascular disc favors the distribution of forces (Nickel *et al.*, 2003), for what it must be properly lubricated (Tanaka *et al.*, 2008). The TMJ can result loaded mainly under masseters muscles activity (Koolstra *et al.*, 1988a, 1998b; del Palomar *et al.*, 2008) receiving larger reaction forces on the non-chewing or nonworking (Academy of Prosthodontics, 2005) side (Hylander, 1979; Smith *et al.*, 1986).

There are some main concepts addressed in this work, which will be defined below:

***Mastication*** (Academy of Prosthodontics, 2005), or ***chewing***, is the process of preparing food for swallowing and digestion. It seems to be controlled by the central nervous system (CNS). (Hoogmartens *et al.* 1987, Pond *et al.* 1986). Normal mastication in humans favors one side and then the other; however, to chew consistently on the same side is referred to as the "preferred", "habitual chewing side" or "masticatory laterality". Chewing function has a specific biodynamic; its main phase is the last dental phase, during it, the jaw follows an anteromedial direction to reach the occlusal phase in which the food is chewed.

The teeth, main food mastication agent, are no-rigidly articulated to the jawbones through a gonfosis (from "gonfos", clove), which includes the periodontal ligament, prepared to distribute occlusal forces (Rios *et al.*, 2008; Termsuknirandorn *et al.*, 2008). The number of occluding pairs of teeth was closely correlated with chewing efficiency (Helkimo *et al.,* 1975; van der Bilt *et al.*, 1994).

Normal mastication in humans is mainly on the right or left sides alternately (Figure 1). To chew consistently by the same side is referred to as preferred chewing side or laterality (Hildebrand, 1936; Ahlgren, 1967$_{a,c}$; Christensen and Raude, 1985$_{a,b,c}$,; Mioche *et al.*, 2002). Ahlgren reported that the chewing pattern is characteristic of an individual (Ahlgren, 1967$_{a}$). Some authors suggested that the masticatory laterality is controlled by the nervous central system (NCS) while the occlusal factors are not the chief determinants (Hoogmartens *et al.*, 1987; Nissan *et al.*, 2004; Pond *et al.*, 1986).

Hildebrand stated (Hildebrand, 1936) that "The teeth appear, as a rule, to exercise an influence on the choice of the masticatory side in such wise that the side is chosen where most teeth are in contact during lateral gliding, i.e., where there is the best articulation (dental occlusion)". Masticatory function can influence the growth of the stomatognatic structures (Shimomoto *et al.*, 2007; Ito *et al.*, 1988; Ishida *et al.*, 2009); the TMJ alteration could lead to retarded mandibular growth on the ipsilateral side (Legrell and Isberg, 1998, 1999; Legrell *et al.*, 1999), the extent corresponding to ipsilateral hemimandibular retrognathia and facial asymmetry in man.

The relationship between the use of one habitual chewing side and the dynamic peripheral factors involved in temporomandibular disorders is not fully understood (Pond *et al.* 1986, Pullinger *et al.*, 1993; Szentpétery *et al.*, 1987; Racich 2005; Reinhardt *et al.*, 2006; Diernberger *et al.*, 2008), neither is the impaired masticatory function influence on TMD (Al-Hadi, 1993; Pond *et al.*, 1986; Belser *et al.*, 1985; Hoogmartens *et al.*,

1987b; Mohl, 1993$_{a}$; Nissan *et al.*, 2004; Gesch *et al.*, 2005; Reinhardt *et al.*, 2006; Luther, 2007$_{a,b}$).

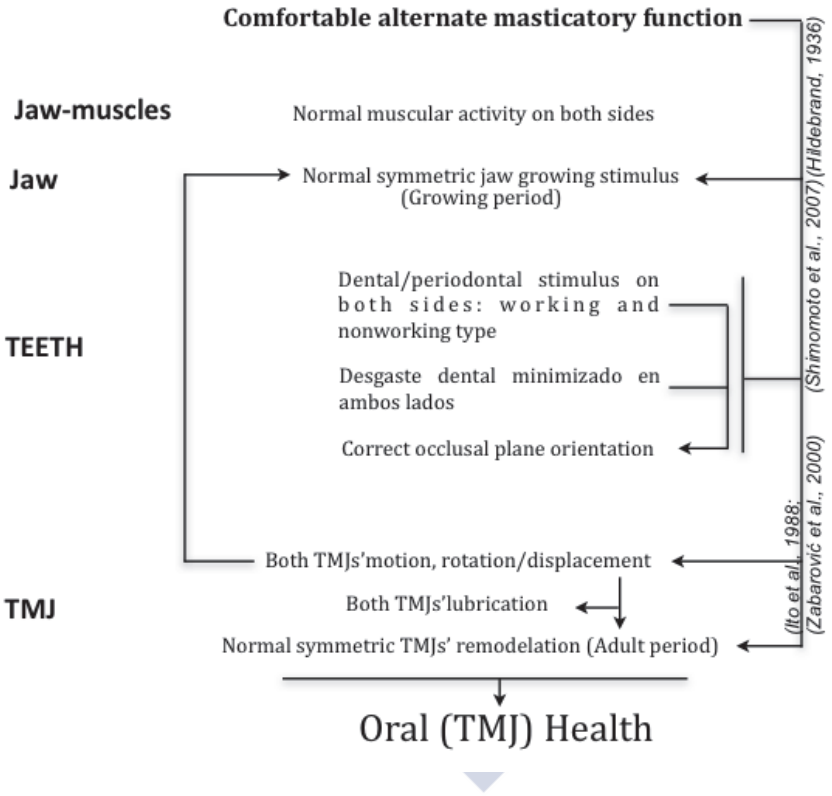


*Fig. 1.- Physiology of the alternate unilateral mastication: A proposed model.*

To chew, during the last chewing cycle, the power stroke, the jaw follow an anteromedial direction to reach the occlusal phase (Gibbs and Lundeen, 1982) in which the food is chewed. Jaw movements are guided by the chewing (working) TMJ, acting essentially as a fulcrum (Miyawaki *et al.*, 2001), the nonworking gliding TMJ (Miyawaki *et al.*, 2001) and the anterior lateral guidance, which is determined by the dental anatomy

(Ferrario *et al.*, 1996). Nonworking side TMJ determines the condylar path (Gysi and Wayne, 1910); thus, the ipsilateral-guidance and the contralateral condylar path (Academy of Prosthodontics, 2005) are the main determinants of the jaw-lateral horizontality and both are richly innervated (from TMJ capsule and periodontal mechanoreceptors and free endings).

*Lateral guidance.* Lateral guidance angles are usually defined and recorded in the frontal plane and measured in relation to the horizontal (bipupilar) line (Figures 2, 3). Although no patient group showed no lateral guidance side-differences (Ferrario *et al.*, 1992), flatter lateral guidance in the temporomandibular disorders side was reported in asymptomatics (Ferrario *et al.*, 1996).

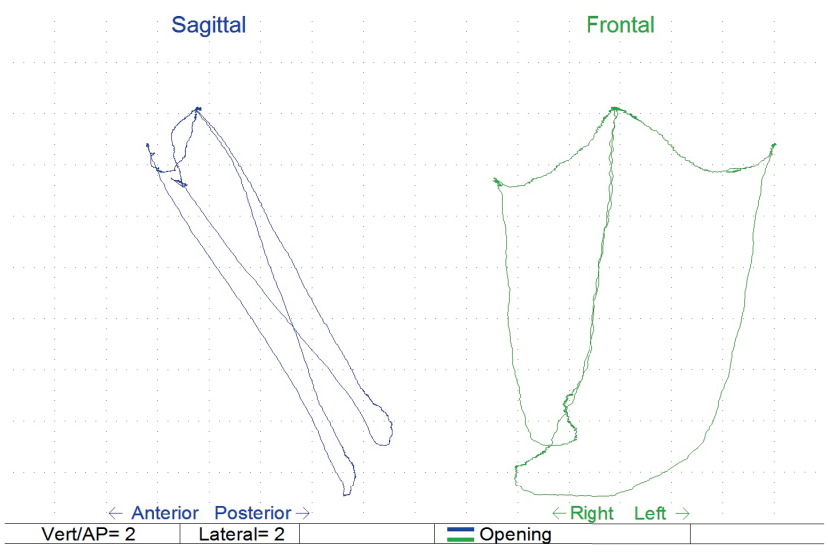


*Fig. 2.- Original picture of the frontal plane lateral guidance recordings. Left lateral guidance is flatter than right lateral guidance suggesting left habitual chewing and left TTM.*

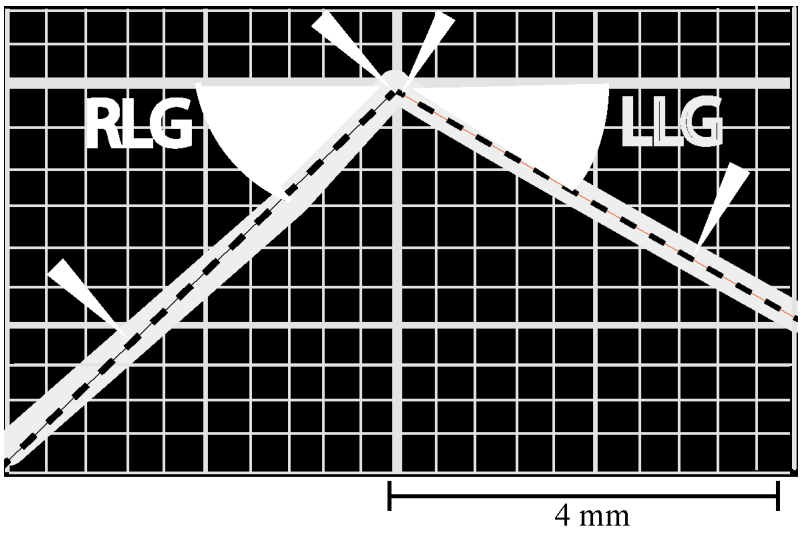


***Fig. 3.**- How frontal plane lateral guidance angles were measured: 3 mm from the maximal intercuspal position respect to the Frankfort horizontal plane.*

*Condylar path* tracings, no rotating but gliding ones, can be registered in a parasagital plane in relation to the Frankfort horizontal line (Figures 4, 5, 6) by a mechanical device (Gysi and Wayne, 1910; Preti *et al.*, 1982; Zamacona *et al.*, 1992); the diagnostic accuracy for temporomandibular disorder's diagnosis of the electronic devices (Shields *et al.*, 1978; Theusner *et al.*, 1993) has been questioned (Mohl *et al.*, $1990_{a,b,c}$; 1993; Gonzalez et al., 2008). Condylar path angles inclination was correlated with the steepness of the *temporalis* eminence (Corbett *et al*, 1971; Isberg *et al.*, 1998), which is completely flat at birth, and reaches its full development at the age of twelve (Humphreys, 1931). Mean CP angle-values showed ethnic (42.8° for whites and 33.9° for Australian aborigines; but no significant sides-differences (Moffett, 1968; Baqaien *et al.*, 2007; Reicheneder *et al.*, 2009).

Although genetic influence (Angel, 1948), the TMJ undergoes continuous morphological alteration throughout adult life (Poikela *et al.*, 1997; Hinton, 1981; Zabarovic *et al.*, 2000). Loading in the TMJ may stimulate remodeling which is an essential biological response to normal functional demands (Smartt *et al.*, 2005). Increased eminence steepness was associated to TMD internal derangement (Atkinson and Bates Jr., 1983; Kerstens *et al.*, 1989); other authors suggested decreased steepness in temporomandibular disorder patients (Ren *et al.*, 1995).

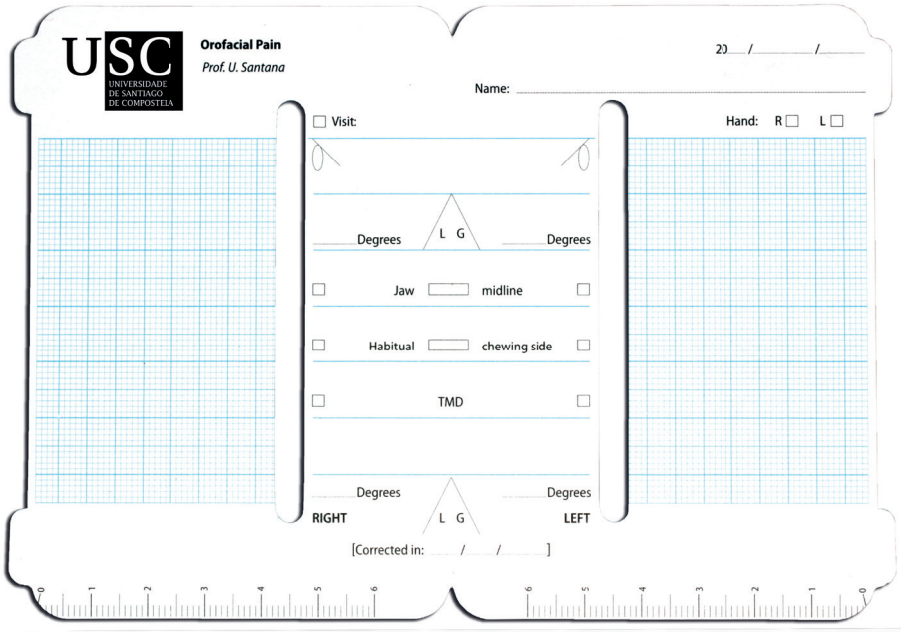


***Fig. 4.*** *- Template for condylar path recordings (Parasagittal plane axiography).*

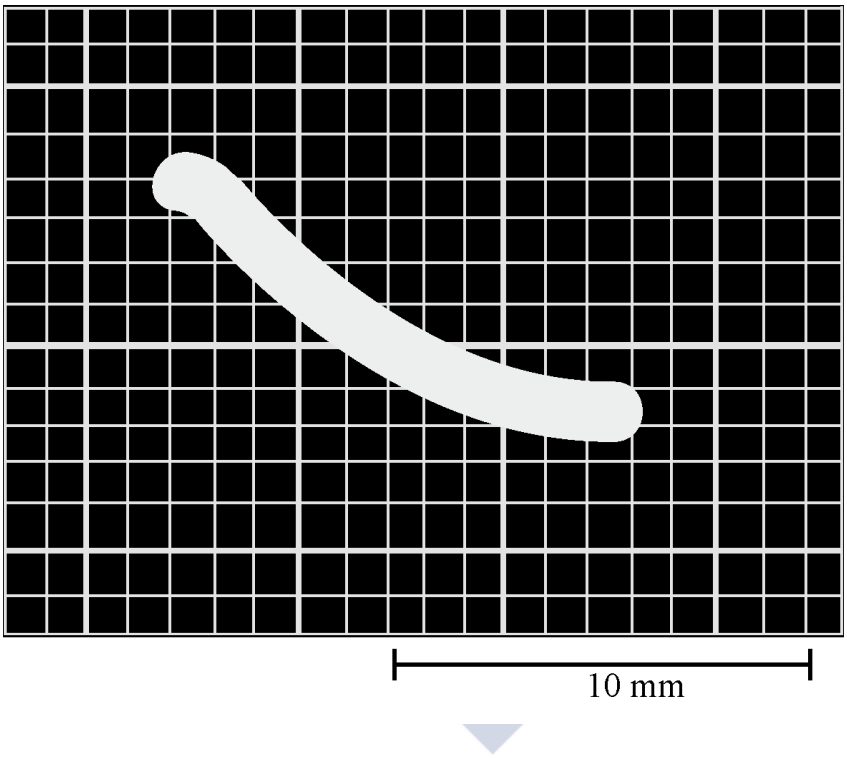


***Fig.5**.- Detail of the parasaggital plane condylar path recordings; the first 3-4 mm of the initial part with upper concavivity were used to measure corresponding angles.*

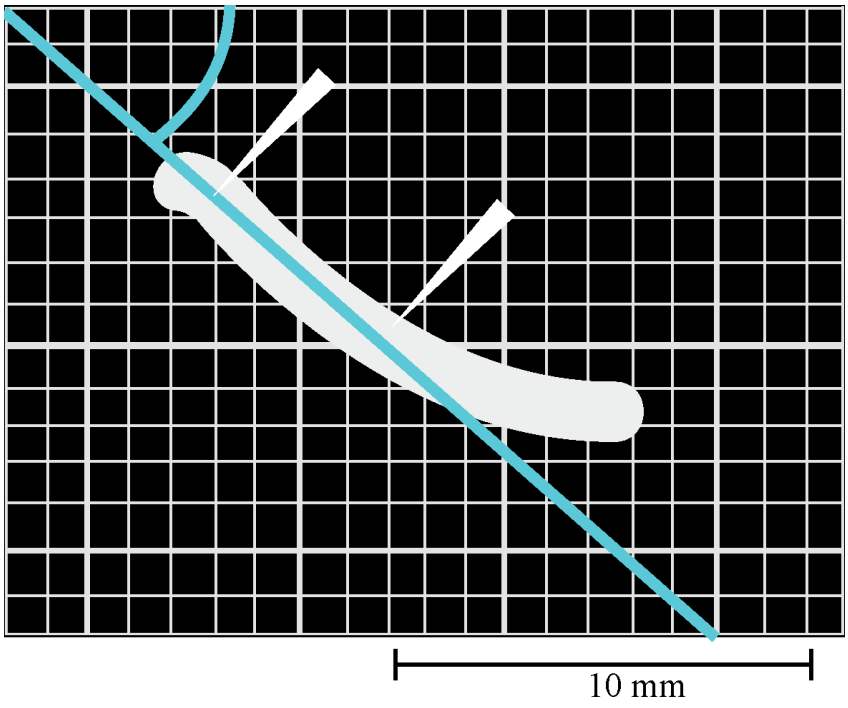


*Fig. 6.- How condylar path angles were measured.*

***Pain*** is defined as a subjective unpleasant sensory and emotional experience associated with actual or potential tissue damage or described in terms of such damage (Academy of Prosthodontics, 2005; Huskisson, 1974). The International Association for the Study of Pain defines *Chronic Pain* as: "pain which persists past the normal time of healing". With non-malignant pain, three months is the most convenient point of division between acute and chronic pain, but for research purposes six months will often be preferred (Merskey, 1994) (Von Korff and Dunn, 2008).

Pains that originate from the musculoskeletal structures of the masticatory system are included in a category of pain complaints collectively known as temporomandibular disorders (Okeson, 1996; Liljeström *et al.*, 2005). Pain in the temporomandibular region appears to be relatively common, occurring in approximately 10% of the population over age 18; it is primarily a condition of young and middle-aged adults, rather than of children or the elderly, and is approximately twice as common in women as in men (LeResche, 1997). Although most men and women are symptom-free and have similar positive magnetic resonance images (MRIs) for TMD (Bernhardt *et al.*, 2007), 15% of adults, mainly women (Al-Jundi *et al.*, 2008), seek treatment for TMD symptoms.

***Temporomandibular joint disorders*** embrace various clinical problems involved with the TMJ, the masticatory muscles, and associated structures. The severity of these conditions may range from noticeable but clinically insignificant signs to seriously debilitating pain or dysfunction. The signs and symptoms associated with various subclassifications of TMD include jaw and/or facial pain, limited mouth opening, changes in jaw relationship, a variety of joint sounds and degenerative changes in the TMJ itself. The most common complaint is pain that may be accompanied by difficulty in mouth opening and following any activity requiring significant jaw movement (Eliav *et al.* 2003, De Leeuw and Klasser, 2013).

Temporomandibular joint disorders are considered to be unexplained clinical conditions (Aaron and Buchwald, 2001), the exact causes of most

TMDs, with the exception of the traumatic aetiologies, remain largely unknown or are speculative (Greene, 2006; Tanaka *et al*., 2008; De Leeuw and Klasser, 2013), but it is considered multifactorial and includes both physical (peripheral) and psychosocial (central) factors. (Diatchenko *et al*., 2005); pain and limited jaw opening are the main symptoms. (De Leeuw and Klasser, 2013). Subjects with TMD-pain alter the recruitment of their jaw muscles (Nielsen *et al*., 1990). Free nerve endings act as nociceptors activated by noxious stimulation such as temporomandibular joint (TMJ) overloads and/or masticatory muscles ischemia, if it is prolonged and associate with muscle contractions (Milam *et al*., 1998; Sessle, 2000a; Tanaka *et al*., 2008). A decrease of motor unit firing rate has been correlated to the intensity of muscle pain, but the central mechanisms involved remain unclear (Farina *et al*., 2004).

The suggested chief etiologic factor is TMJ overloading, (Tanaka *et al*. 2008) resulting in the collapse of joint lubrication and the generation of free radicals, thereby causing hypoxia when capillary perfusion pressure is exceeded. (Nitzan DW (2001), Overloading of the TMJ can originate in the masseter muscles, (Koolstra *et al*. 1988 a; 1988b; del Palomar *et al*. 2008; Hylander, 1979) mainly on the nonworking side, (Smith *et al*. 1986) and can initiate bone remodeling. (Smartt *et al*. 2005, Ren *et al*.1995, Poikela *et al*.1997, Hinton,1981).

Ethical concerns make it impossible to directly measure TMJ loading in humans because the TMJ is a very inaccessible joint and the insertion of measuring equipment such as pressure-sensitive devices would involve major disruption for the patient and as well as modifying the biological environment of the joint. Experimental studies in animals have shown that the TMJ is a stress-bearing joint (Hylander, 1977); this conclusion was supported by a later study by Brehnan *et al*. (1981), who recorded greater loading of the TMJ for incisal (3–4 lb) than for molar (1–3 lb) biting at the condyle in a macaque (*Macaca arctoides)*. Finite element analysis has suggested that forces generated during incisal biting increase TMJ loading (del Palomar *et al*., 2008). During incisal biting, no muscles are in

a position to distract the condyles, and consequently all elevator muscles combine to direct the condyles in an antero-superior direction in centric relation and also to keep them loaded against the *eminentiae* (Tanaka *et al.*, 1994; Korioth and Hannam, 1994; Hannam and McMillan, 1994; Dawson, 1995; Farella *et al.*, 2008).

The diagnostic value of sEMG is not yet clearly established. A recent review concluded that no evidence exists to support the use of surface electromyography to diagnose TMD (Al-Saleh *et al.*, 2012). Another study assessed sEMG activity during rest and used the proportion of participants to find a cutoff score intended to differentiate those with myofascial pain from those with no pain; the authors, however, concluded that no cutoff point could be established to discriminate between those with symptoms and those without (Glaros *et al.*, 1997). Other authors (De Felício *et al.*, 2012) have suggested that sEMG and other derived factors can discriminate between women with TMD and those without. Some characteristics of the muscular function of TMD have been reported (Santana-Mora *et al.*, 2009; De Felício *et al.*, 2012), but no specific criterion or cutoff point has been reported that accurately discriminate between healthy individuals and those with TMD.

Because individuals with chronic TMD change the pattern of their jaw movements (Nielsen *et al.*, 1990; Gramling et al., 1997), sEMG evaluations have been considered a promising method of evaluating the muscular activity and function of individuals with TMD (Rugh and Montgomery, 1987; Glaros *et al.*, 1989; Pinho *et al.*, 2000; Widmalm *et al.*, 2007; Santana-Mora *et al.*, 2009; De Felício *et al.*, 2012; Hugger *et al.*, 2012) and their response to therapy (Santana and Mora, 1995). Lower resting raw sEMG activation was observed in the control group than in those individuals with TMD (Rugh and Montgomery, 1987; Glaros *et al.*, 1989; Ferrario et al., 1993; Ferrario et al., 2000; Pinho *et al.*, 2000; Santana-Mora *et al.*, 2009). Moreover, more asymmetry and more unbalanced contractile normalized sEMG activities of the contralateral masseter and temporal muscles were reported during static (De Felício

*et al.*, 2012) and dynamic (De Felício *et al.*, 2013) oral tasks. Indeed, the American Dental Association has accepted surface electromyography (sEMG) as an aid in the diagnosis of TMD (ADA, 1996).

The muscle co-activation determines the magnitudes and directions of TMJ loads (Throckmorton *et al.*, 1990; Tanaka *et al.*, 1994; Trainor *et al.*, 1995; Nickel *et al.*, 2012). Little information is available about the specific contribution of each muscle; for instance, a 1:1 ratio has been reported for the temporalis and masseter muscles during isometric incisal biting, but a ratio closer to 3:1 between the surface electromyography (*s*EMG) magnitude of the pair of triple masseters (182 μV) to the temporalis (69 μV) during mean - 30 to 60% of maximal - incisal effort (Throckmorton *et al.*, 1990). The specific contribution of each individual muscle force to the total incisal bite forces and resultant TMJ loads is unknown. The proportion contributed by each muscle seems to differ depending on the tooth position when biting (Throckmorton *et al.*, 1990) and also on the magnitude of the generated loads (Sowman and Türker, 2008). The activity of these muscles is influenced more by the position and magnitude of occlusal forces than by TMJ loads (Throckmorton *et al.*, 1990). Forces generated by the masticatory muscles are influenced by neural factors transmitted by the Golgi tendon organs which are highly sensitive tension receptors, and by the periodontal ligament (Bakke *et al.*, 1992) but the TMJ's mechano-receptors also play a part in preventing oromandibular damage from excessive loading (Erkelens and Bosman, 1985; Sowman and Türker, 2008).

The bite-force increases in relation to muscle activity (Hidaka *et al.*, 1999). Muscle forces act on the structures of the masticatory apparatus and may generate excessive loading on the tooth row and/or TMJs (May and Garabadian, 2000). Maximal bite-force magnitude is mainly dependent on factors associated with the masseter muscles (Koolstra *et al.*, 1988a, 1988b; Van Spronsen *et al.*, 1996), and to a lesser extent, other craniofacial factors (Raadsheer *et al.*, 1999). The máximum bite-force of masticatory muscles can be generated during clenching (Koolstra *et al.*, 1988a), and

consequently the greatest EMG values may be registered (Figure 7), according to previous reports (Van Eijden *et al.*, 1993; Erhardson *et al.*, 1993; Wood, 1987).

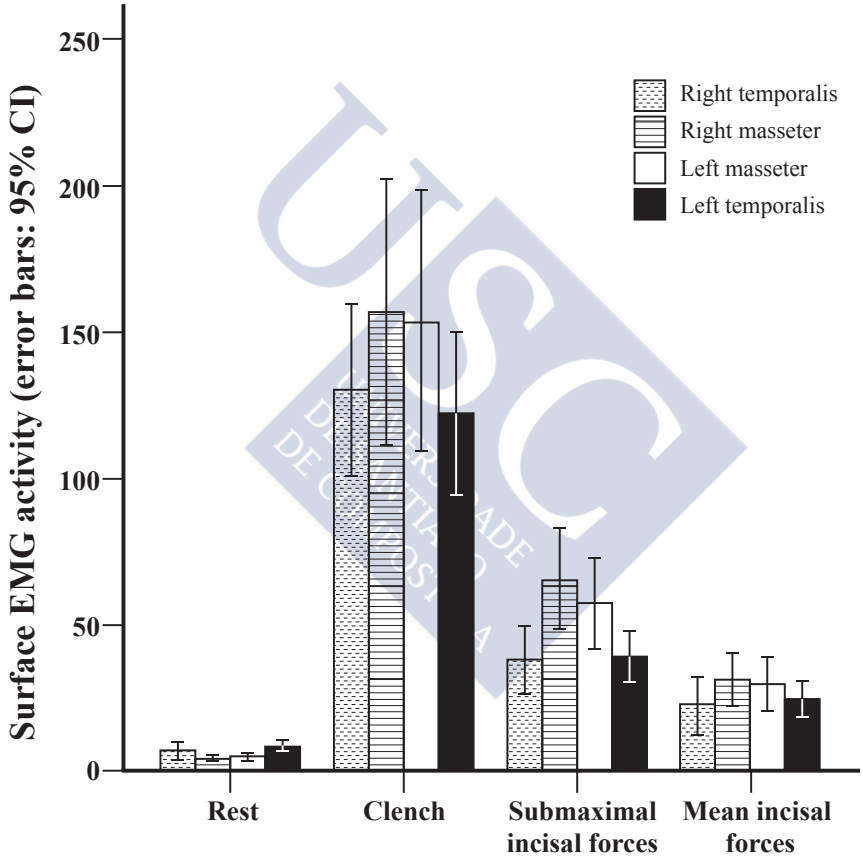


*Fig. 7.- EMG activity (µV) of jaw muscles during different tasks.*

Maximum EMG activity is greater in pain-free subjects tan in patients with TMD pain (Helkimo *et al.*, 1975; Fogle and Glaros, 1995). Though substantially lower bite-force has been observed in TMD patients than in controls, such force is similar on the disordered and non-disordered sides (Molin, 1972). In order to avoid overloading, the clenching bite-force adjusts to a position where it is well balanced (Hidaka *et al.*, 1999), and muscle forces are directed to minimize joint loads and muscle efforts (Nickel *et al.*, 2003).

Though mathematical and biomechanical models have explained the effect of the force of masticatory muscles (Smith *et al.*, 1986; Koolstra *et al.*, 1988a; Ferrario and Sforza, 1994), in vivo studies of EMG activity are required to substantiate the findings of these models given that the observations of in vitro models may not be extrapolated to complex clinical contexts.

We speculate that if during isometric incisal biting the activity of the temporalis pair predominates, then the TMJ remains "protected" against overloading; however, if the masseter (perpendicular to the *eminentiae*) muscles predominate, an increase in TMJ loading should be expected. Moreover, we assume that generating muscular forces requires their activation and that this activation can be recorded by *s*EMG (Figure 8). These *s*EMG recordings showed linear relationships with generated occlusal loads on a short-term basis (Ferrario *et al.*, 2004). Thus, although *s*EMG data do not match occlusal forces, *s*EMG magnitude can indirectly predict, with linear relationships on a short-term basis, the effective magnitude of occlusal loads generated by jaw-muscles. Based on jaw-biodynamics during incisal biting, in which the jaw seems to act as a class III lever with three points (the incisal point as the effort arm and two TMJ points as the resistance arms with the muscular elevator point between them, but nearest to the TMJ points), and on model predictions (Tanaka *et al.*, 1994; Korioth and Hannam, 1994; del Palomar *et al.*, 2008), TMJ-loads could indirectly and reasonably be inferred.

The only causal factor universally accepted in the literature is TMJ overloads (Tanaka *et al.*, 2008) and therefore a study was designed to assess the influence of the charges on the incisors and their possible repercussion on the TMJs. This study included evaluation of the EMG activity, simultaneously recording voluntary submaximal loads on the incisors; showing that the incisal bite is a complex task, which seems to be designed to protect the TMJs during medium intensity forces, but when performing submaximal forces it behaves like a system designed to make incisal forces with a big commitment of TMJs because of the most selective effort of the masseter muscles (Santana-Mora *et al.*, 2014).

It is obvious that TMJ loads are generated by the masticatory muscles, and therefore our team has conducted investigations of muscle activity; firstly validating the methodology used in the USC and comparing healthy subjects with unilateral TMD patients (80% of TMD´s are unilateral) (Santana-Mora *et al.*, 2009). This study was completed with another that showed some EMG capacity to discriminate between healthy subjects and patients (Santana-Mora *et al.*, 2014). In this field, there has been a comment published in Pain Medicine indicating some limitations of published studies (Santana-Mora and Santana-Penín, 2013).

However, most kinds of pain, for example myofascial pain, are not the result of myospasm but centrally mediated myalgia, placing in doubt any absolute association between muscular pain and high sEMG muscle activity (Okeson, 2008). Clinical evaluation allows the diagnosis of TMD, although it does not usually explain the etiology or contribute to a therapy plan. If sEMG could diagnose TMD by assessing specific pathological muscular biodynamics, it could theoretically be used to monitor the effect of therapy, detect subclinical TMDs, or even prevent this pathology. sEMG, however, should never replace clinical examination.

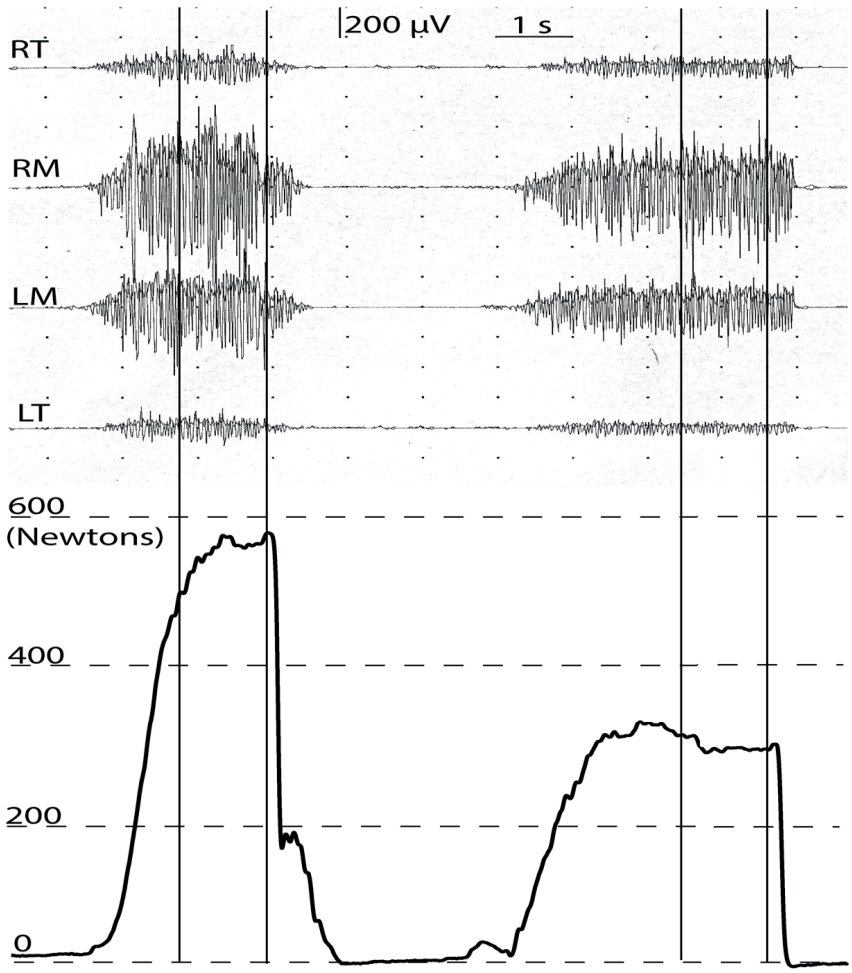


***Fig. 8.***- *Graphic recordings of sEMG activity of jaw muscles (upper part) and incisal loading (lower part) during submaximal and mean (50%) effort. RT, right temporalis; RM, right masseter; LM, left masseter, LT, left temporalis.*

Information of the masticatory laterality and temporomandibular disorders association is scarce. It was stated that one habitual chewing side is more frequent in patients than in non-symptomatic subjects (Agerber and Carlsson, 1975; Szentpétery *et al.*, 1987; Reinhardt *et al.*, 2006; Al-Hadi, 1993). This research demonstrated the association of factors or characteristics, specifically, condylar path steepening, anterior lateral guidance reduction and habitual chewing function on the affected side, justifies a new, plausibly etiological, denomination: the Habitual Chewing Side Syndrome (HCSS) (Santana-Mora *et al.*, 2013). So far it had not been yet established the association between the habitual chewing side and chronic unilateral temporomandibular disorders.

# Objectives and study hypothesis

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# Objectives and study hypothesis

Summarizing, the TMD is considered a chronic condition, for which the cause and treatment are not yet established. TMJ overloads are a recognized factor (Tanaka *et al.*, 2008). The diagnostic of TMD is currently clinical, and based in the recognition of the painful structures (DC/TMD) (Schiffman *et al.*, 2014) and, in certain cases, in the MRI and CBCT/Panoramic radiographs. The use of devices for dynamic factors recordings is not recommended (Mohl *et al.*, 1990$_{a,b,c;}$ Mohl *et al.*, 1993$_{b}$).

Our researches suggested an association between symptoms, asymmetry of condylar path and lateral guidances, and impaired chewing function. Thus, the study of this factors is warranted, and described in the first part of this study, including the manuscript entitled "Temporomandibular disorders: the habitual chewing side syndrome". TMJ overloads, and also chewing function (and parafunction, if occur), should be imputed to muscular function, which can be assessed using sEMG. Consequently, the study of the muscular co-activation during several tasks is a promising method to assess jaw-function. This matter is presented in the second part of this work, and in the manuscripts: "Changes in EMG activity during clenching in chronic pain patients with unilateral temporomandibular disorders" and "Surface raw electromyography has a moderate discriminatory capacity for differentiating between healthy individuals and those with TMD: A diagnostic study".

Moreover, sEMG studies can be improved using simultaneous records of effective occlusal loads. Thus, one study reporting muscular co-activation during different occlusal loading was carried out, and reported in the manuscript entitled "Muscular activity during isometric incisal biting".

The aim of this work is to assess an association between functional, dynamic and anatomical characteristics of the masticatory system in patients suffering TMD-pain condition and in healthy groups. With this in mind, our team conducted a series of studies to explain this situation, using strictly the scientific method. In the different articles we sought to check the following *null hypothesis*:

- There is no association between the symptomatic and the habitual chewing side nor condylar path and the lateral anterior guidance asymmetry.

- There are no sEMG differences between symptom-free and unilateral TMD subjects (thus making the selection of a cutoff point based on sEMG scores impossible); neither between patients suffering from right side TMD in contrast to those suffering from left side TMD.

- There are no differences between main jaw closer muscles EMG activity during incisal bite neither correlation between effective incisal loading and the magnitude of the sEMG activity.

The final purpose of this research is to evaluate the correlation between structural and dynamic and functional factors in order to illuminate future research of factors involved in TMD-pain condition to elucidate the contributor factors and causation.

# Methods

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## IRB

The Regional Human Ethics Committee of Galicia (CAEI) approved this study; all participants provided their written, informed consent.

## Ethical issues

Research carried out according to:

— World Medical Association Declaration of Helsinki (2013).

— Organic Law 15/1999, of the 13 of December on the protection of information of a personal nature.

— Royal Decree 1716/2011, of 18 November, regulating the treatment of human biological samples.

## Funding

This study was financed with a grants PI11/02507 from the Institute of Health Carlos III of the Ministry of Science and Innovation of the Government of Spain. It was completed with the equipment granted by the General Directorate of Universities and Research; Department of Education and University. Xunta de Galicia. Official Journal No. 143 Galicia, July 22, 1996. And the Department of Innovation, Industry and Commerce. Xunta de Galicia, April 30, 2004. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscripts or PhD Thesis.

## Competing Interests

The authors have declared that no competing interests exist.

# Articles

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J Electromyogr Kinesiol. 2009 Dec;19(6):e543-9. doi: 10.1016/j.jelekin.2008.10.002. Epub 2008 Nov 28.

# Changes in EMG activity during clenching in chronic pain patients with unilateral temporomandibular disorders.

Santana-Mora U[1], Cudeiro J, Mora-Bermúdez MJ, Rilo-Pousa B, Ferreira-Pinho JC, Otero-Cepeda JL,Santana-Penín U.

**Author information**

## Abstract

The study assessed the differences in electromyographic (EMG) activity recorded during clenching in women with chronic unilateral temporomandibular disorders (TMDs) as compared to control subjects. Seventy-five full dentate, normo-occlusion, right-handed, similarly aged female subjects were recruited. Twenty five subjects presented with right side TMD, 25 presented with left side TMD and 25 pain-free control subjects participated. Using integrated surface EMG over a 1 s contraction, the anterior temporalis and masseter muscles were evaluated bilaterally while subjects performed maximum voluntary clenching. Lower EMG activation was observed in patients with TMD as compared to control subjects (temporalis: 195.74+/-18.57 vs. 275.74+/-22.11, P=0.011; masseters: 151.09+/-17.37 vs. 283.29+/-31.87, P<0.001). An asymmetry index (SAI) was calculated to determine ratios of right to left sided activation. Patients with right-sided TMD demonstrated preferential use of their left-sided muscles (SAI -5.35+/-4.02) whereas patients with left-sided TMD demonstrated preferential use of their right-sided muscles (SAI 6.95+/-2.82), (P=0.016). This unilateral reduction in temporalis and masseter activity could be considered as a specific protective functional adaptation of the neuromuscular system due to nociceptive input. The asymmetry index (SAI) may be a useful measure in discriminating patients with right vs. left-sided TMD.

PMID: 19041265 [PubMed - indexed for MEDLINE]

PLoS One. 2013 Apr 8;8(4):e59980. doi: 10.1371/journal.pone.0059980. Print 2013.

# Temporomandibular disorders: the habitual chewing side syndrome.

Santana-Mora U[1], López-Cedrún J, Mora MJ, Otero XL, Santana-Penín U.

Author information

## Abstract

**BACKGROUND:** Temporomandibular disorders are the most common cause of chronic orofacial pain, but, except where they occur subsequent to trauma, their cause remains unknown. This cross-sectional study assessed chewing function (habitual chewing side) and the differences of the chewing side and condylar path and lateral anterior guidance angles in participants with chronic unilateral temporomandibular disorder. This is the preliminary report of a randomized trial that aimed to test the effect of a new occlusal adjustment therapy.

**METHODS:** The masticatory function of 21 randomly selected completely dentate participants with chronic temporomandibular disorders (all but one with unilateral symptoms) was assessed by observing them eat almonds, inspecting the lateral horizontal movement of the jaw, with kinesiography, and by means of interview. The condylar path in the sagittal plane and the lateral anterior guidance angles with respect to the Frankfort horizontal plane in the frontal plane were measured on both sides in each individual.

**RESULTS:** Sixteen of 20 participants with unilateral symptoms chewed on the affected side; the concordance (Fisher's exact test, P = .003) and the concordance-symmetry level (Kappa coefficient κ = 0.689; 95% confidence interval [CI], 0.38 to 0.99; P = .002) were significant. The mean condylar path angle was steeper (53.47(10.88) degrees versus 46.16(7.25) degrees; P = .001), and the mean lateral anterior guidance angle was flatter (41.63(13.35) degrees versus 48.32(9.53) degrees P = .036) on the symptomatic side.

**DISCUSSION:** The results of this study support the use of a new term based on etiology, "habitual chewing side syndrome", instead of the nonspecific symptom-based "temporomandibular joint disorders"; this denomination is characterized in adults by a steeper condylar path, flatter lateral anterior guidance, and habitual chewing on the symptomatic side.

PMID: 23593156 [PubMed - indexed for MEDLINE] PMCID: PMC3620406 **Free PMC Article**

Pain Med. 2014 Feb;15(2):341. doi: 10.1111/pme.12301. Epub 2013 Dec 19.

# Commentary on Manfredini et al.

Santana-Mora U[1], Santana-Penín U.

**Author information**

**Comment in**

Response to letter by dr. Santana-Penin. [Pain Med. 2014]

**Comment on**

Surface electromyography findings in unilateral myofascial pain patients: comparison of painful vs. non painful sides. [Pain Med. 2013]

PMID: 24354804 [PubMed - indexed for MEDLINE]

J Electromyogr Kinesiol. 2014 Jun;24(3):332-40. doi: 10.1016/j.jelekin.2014.03.001. Epub 2014 Mar 14.

# Surface raw electromyography has a moderate discriminatory capacity for differentiating between healthy individuals and those with TMD: a diagnostic study.

Santana-Mora U[1], López-Ratón M[2], Mora MJ[1], Cadarso-Suárez C[2], López-Cedrún J[3], Santana-Penín U[4].

**Author information**

## Abstract

The use of surface electromyography (sEMG) to identify subjects with chronic temporomandibular disorders (TMD) is controversial. The main objective of this study is to determine the diagnostic accuracy of EMG to differentiate between healthy subjects and those with TMD. This study evaluated 53 individuals with TMD who were referred to the university service and who fulfilled the eligibility criteria during the period of the study. Thirty-eight dental students were also recruited satisfying same eligibility criteria but without TMD. The inclusion criteria were to be fully dentate, have normal occlusion, and be righthanded. The exclusion criteria were periodontal pathology, caries or damaged dental tissues, orthodontic therapy, maxillofacial disease, botulinum A toxin therapy, and psychological disorders. The means of the masseter muscles, right (RM) and left (LM), and temporalis muscles, right (RT) and left (LT), and intraindividual indexes during resting and during clenching were calculated. Raw sEMG activity was used to determine the cutoff points and calculate the diagnostic accuracy of sEMG. The diagnostic accuracy of these variables for a diagnosis of TMD was evaluated by using the Receiver Operating Characteristic (ROC) curve and the area under it (AUC). A new transformed diagnostic variable was obtained by using the Generalized Additive Models (GAM). Optimal cutoff points were obtained where the sensitivity and specificity were similar and by the Youden index. The highest estimated AUC was 0.660 (95% CI 0.605-0.871) corresponding to the rLT variable during rest. When rLT and rACTIVITY (differences divided by sums of temporalis versus masseter muscles) were considered as a linear combination, the AUC increased to 0.742 (95% CI; 0.783-0.934). In conclusion, the raw sEMG evaluation of rest provided moderate sensitivity and specificity to discriminate between healthy individuals and those with TMD. The use of the indexes (mainly assessing the dominance of temporalis over masseter muscles during rest) is strongly recommended to increase the discriminatory capacity of raw sEMG evaluation.



**KEYWORDS:** Diagnosis; EMG; Jaw muscles; Pain; TMD

J Biomech. 2014 Dec 18;47(16):3891-7. doi: 10.1016/j.jbiomech.2014.09.007. Epub 2014 Oct 16.

# Muscular activity during isometric incisal biting.

Santana-Mora U[1], Martínez-Ínsua A[2], Santana-Penín U[2], del Palomar AP[3], Banzo JC[3], Mora MJ[2].

**Author information**

## Abstract

This study attempted to estimate TMJ loading during incisal loading using a custom load-cell device and surface electromyographic (sEMG) recordings of the main jaw closers to assess the outcome correlation. Study participants were 23 healthy volunteers. The incisal loads having submaximal and mean intensity were recorded using a calibrated electronic load cell; simultaneously, surface electromyography (sEMG) of the right and left masseter and temporalis muscles was recorded. Readings of the resting, clenching in maximal and submaximal intercuspal positions and mean (50%) incisal loads were recorded. Clenching sEMG activity was used as a reference for normalization. The mean (SD) submaximal incisal load recorded was 498 (305.78)N, and the mean at 50% of the submaximal load was 268.93 (147.37)N. Mean (SD) sEMG activity during submaximal clenching was 141.23 (87.76)μV, with no significant differences between the four muscles. During submaximal voluntary incisal loading, the normalized mean sEMG activity was 49.99 (34.54)μV %, and 27.17(15.29)μV % during mean (50%) effort. The incisal load was generated mainly by the masseter muscles, as these showed a positive correlation during mean but not during submaximal effort. In the edge-to-edge jaw position, the mean incisal load effort seems to be physiological, but excessive TMJ loads can be expected from chronic or excessive incisal loading. In conclusion, incisal loads require the activity of the masseter muscles, which show a positive correlation between sEMG activity and effective incisal loads during mean, but not during submaximal, effort, and the masseter muscles are dominant over the temporalis muscles during submaximal incisal biting.



**KEYWORDS:** Bite forces; EMG; Loads; TMJ; Temporomandibular disorders

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# General Discussion

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# General Discussion

This is the first work showing that chronic unilateral temporomandibular disorders mainly affect the habitual chewing side, the side with higher condylar path and flatter lateral anterior guidance angles (Santana-Mora *et al.*, 2013); it supports a new plausibly etiological denomination for temporomandibular joint disorders: "the Habitual Chewing Side Syndrome", that could replace the unspecific, symptoms based, "TMJ disorders-pain".

Moreover, this study stresses the interest of the sEMG recordings for TMD patients: it has a moderate capacity to discriminate between healthy and TMD-patients, and a high capacity to discriminate between left and right TMD condition.

Finally, this study shows that mean incisal loads requires the equilibrated activation of the jaw elevator muscles but submaximal incisal loading are performed mainly with the activation of the masseter muscles, which allow us to infer a increase of the TMJ-loads.

***Rational***

The current available information reports that the main factor for chronic TMD is TMJ load (Tanaka *et al.*, 1994; Koolstra *et al.*, 1988a, 1988b; Hannam and McMillan, 1994; del Palomar *et al.*, 2008). However, other

factors could be considered contributors. Based on the physiology of the masticatory system, we could assume that the motion of the TMJs plays a role: the working-side TMJ is almost static, rotating and fulcrum joint. During function, the lower condyle motion does not allow the exchange of metabolites; consequently, the alternate use of both sides to chew, could be a critical characteristic in a physiological chewing. In addition, different TMJ remodeling should be expected from functional characteristics (Isberg, Westesson, 1998). Thus, different condylar path tracings and angles could be recorded from habitual and non-habitual chewing sides.

Because available information reported an association between dental status, occlusal characteristics and chewing function (Hildebrand, 1936; Ahlgren, $1967_b$), lateral guidance recordings (Ferrario et al., 1992, 1996) and measured angles could be different on the symptoms and on the non-symptoms sides. These assumptions supported the objectives of the first part of this study.

Because TMJ loads are generated by jaw-muscles (Tanaka *et al.*, 2008), and jaw-closers muscles (mainly masseters) are the mains responsible for TMJ-loads (Koolstra *et al.*, 1988a) we attempted to assess the activity of jaw elevator muscles. The activity of jaw elevator muscles can be recorded using sEMG devices, and we have studied some aspects of muscular co-activation using this technique.

We have shown the sEMG activity of jaw muscles on healthy and on TMD-pain patients and made comparisons; besides, we attempted to demonstrate the diagnostic capacity of the sEMG evaluations in groups of healthy people and TMD-patients. Previous studies on TMD has been assessing TMD patients, but with no consideration for the concept that this syndrome is usually unilateral. The concept of "TMD-patient" was reconsidered in our work demonstrating the clinical relevance of the (typical) "unilateral TMD condition". This aspect allow us to consider that, although it is possible to consider general contributors

(psicobiological factors), local functional ones could plays a significant contributor role.

One first study revised the literature and described the methodology and reliability of sEMG evaluations showing the asymmetry of muscular activity in chronic unilateral TMD-pain patients and including a similar group of healthy controls (Santana-Mora *et al.*, 2009); a second article demonstrated the capacity of sEMG evaluations to discriminate chronic TMD-pain patients from healthy subjects, using the ROC curves (Hanley, McNeil, 1982; Sing et al., 2009) and the corresponding AUC (Santana-Mora *et al.*, 2014). It may be of interest to researchers and clinicians who seek to obtain valuable information inherent to the EMG, while respecting the interpretation, and probably to detect preclinical TMD condition. In this way, in addition, we made a letter addressed to improve the methodology of sEMG study design and reporting (Pain Medicine, 2014).

Because information on muscle co-activation can be improved performing simultaneously occlusal forces recordings, we simultaneously used a sEMG diagnostic device (Nicolet One, Nicolet Biomedical, Viking select), and a previously calibrated customized load-cell to assess some oral tasks, and we described the muscular co-activation during symmetrical incisal loading (J Biomech, 2014). Previous information showed different TMJ-loads depending of the placement of the ocllusal loads, being lower when oclusal loads are performed on the posterior sectors. However, author assumed that the pater of muscular coactication is dependent of the placement, but not dependent of the other factors, as the occlusal forces-intensity. We have been designed a study to assess the muscular co-activation during symmetrical incisal-biting of different intensity: submaximal and mean (50%).

For the first time we have demonstrated a correlation between symptoms side and the muscular co-activation in unilateral chronic unilateral TMD-pain patients, stands out the clinical significance of EMG evaluations in Dentistry.

*Avoiding harms*

One important aspect in research, according to Helsinki declaration (JAMA, 2013), is to avoid any harm. The diagnostic procedures used in our TMD evaluation, including axiography and gnatography recordings, can be considered absolutely uninvasive procedures. Maximal incisal bite could promote accidental damage on incisal edges. Thus, we made all effort to design the bite-forces device and bite procedure to avoid accidental incisal damage. Firstly, we used no maximal but submaximal incisal loads; and secondly, the design of the device was carefully build allowing a safe and confortable biting. Recordings of condylar path and lateral guidance angles or sEMG studies do not promote any change, being absolutely uninvasive procedures.

**Table 1**. Standard normal deviate ($Z_{crit}$) corresponding to selected significance criteria and CIs

| Significance Criterion * | $Z_{crit}$ Value † |
|---|---|
| .01 (99) | 2.576 |
| .02 (98) | 2.326 |
| .05 (95) | 1.960 |
| .10 (90) | 1.645 |

** Numbers in parentheses are the probabilities (expressed as a percentage) associated with the corresponding CIs. Confidence probability is the probability associated with the corresponding CI.*

*† A stricter (smaller) significance criterion is associated with a larger $Z_{crit}$ value. Values not shown in this table may be calculated in Excel version 97 (Microsoft, Redmond, Wash) by using the formula $Z_{crit}$ _ NORMSINV(1_(P/2)), where P is the significance criterion (Eng, 2003).*

*Subjects under study. Sample sizes determination, for comparative research studies.*

Sample size calculation simply involved selecting an appropriate equation (Cantor, 1996). For a study comparing two means, the equation used was:

$N = (\sigma^2 (Z_{crit} + Z_{pwr})^2) / D^2$ (Pagano *et al.*, 2000; Eng, 2003)

Where N is the total sample size (the sum of the sizes of both comparison groups), $\sigma$ is the assumed SD of each group (assumed to be equal for both groups), the $Z_{crit}$ value is that given in **Table** 1 for the desired significance criterion, the $Z_{pwr}$ value is that given in **Table** 2 for the desired statistical power, and D is the minimum expected difference between the two means. Both $Z_{crit}$ and $Z_{pwr}$ are cutoff points along the x axis of a standard normal probability distribution that demarcate probabilities matching the specified significance criterion and statistical power, respectively. The two groups that make up N are assumed to be equal in number, and it is assumed that two-tailed statistical analysis will be used. Note that N depends only on the difference between the two means; it does not depend on the magnitude of either one.

**Table 2**. Standard normal deviate ($Z_{pwr}$) corresponding to selected statistical powers

| Significance Criterion | $Z_{pwr}$ Value * |
|---|---|
| .80 | 0.842 |
| .85 | 1.036 |
| .90 | 1.282 |
| .95 | 1.645 |

** A higher power is associated with a larger value for $Z_{pwr}$. Values not shown in this table may be calculated in Excel version 97 (Microsoft, Redmond, Wash) by using the formula $Z_{pwr}$ = NORMSINV (power). For calculating power, the inverse formula is power = NORMSDIST ($Z_{pwr}$), where $Z_{pwr}$ is calculated from Equation by solving for zpwr (Eng, 2003).*

*Group selection*

According to the studies purposes, different people were selected and included. The randomized controlled clinical trial "The habitual chewing side syndrome" included 21 participants, homogeneous regarding dental status and suffering from chronic unilateral temporomandibular joint disorders pain.

Similar sample characteristics were used to select a group of patients with chronic unilateral temporomandibular joint pain with the purpose of assessment of sEMG activity. The study assessed the differences in electromyographic (EMG) activity recorded during clenching in women with chronic unilateral temporomandibular disorders (TMDs) as compared to control subjects; twenty five subjects with right side TMD pain, 25 presented with left side TMD pain and 25 pain-free control subjects participated (Santana-Mora *et al.*, 2009).

Another study intended to determine the value of sEMG in the diagnosis of TMD included 91 subjects: This study evaluated 53 individuals with TMD pain who where referred to the university service and fulfilled the eligibility criteria during the period of the study. Thirty-eight dental students were also recruited satisfying same eligibility criteria but without TMD pain as control group. The inclusion criteria were to be fully dentate, have normal occlusion, and be right handed (Oldfield, 1971). For all studies the sample size was previously determined according to the equation previously presented on this section.

To assess the incisal loads and their relationship to the co-activation of the elevator muscles of the jaw, 23 healthy adult subjects where evaluated. It is reasonable to assume that the homogeneity of the sample enhances the internal validity of the study, thus some dependent variables (i.e., age, gender, hemispheric-dominance, and full-dentate normo-occlusion) have been excluded to homogenize both groups under study, which drastically reduced the sample size. The main negative consequence of such a homogeneous

study design was that male patients were not evaluated and, due to gender differences in the central processing of the nociceptive input (Sarlani and Greenspan, 2005), these results should not be extrapolated to males *a priori*. The decision to limit the age range from 18 to 22 years was taken due to the age of the sample (dentistry students), which also coincides with the peak of high prevalence of TMD (LeResche, 1997). All subjects were Caucasian, and their height and weight were into the normality. Because of the controversy concerning the influence of peripheral dental factors on temporomandibular disorders (Pullinger *et al.*, 1993) and on the habitual chewing side, (Hoogmartens *et al.*, 1987, Pond *et al.*, 1986; Varela , 2003) only completely dentate participants with normal occlusion and suffering from chronic temporomandibular disorders were selected (Dworkin and LeResche, 1992). This sample was a subset of participants under the care of a public hospital with a catchment area of more than one million people and so can be considered representative of the general population.

Regarding the methodology and study design the following points will be addressed and discussed:

**I. TMD: The Habitual Chewing Side Syndrome.**
**II. TMD: sEMG studies.**
**III. Correlation Between sEMG activity of jaw muscles and incisal loading.**

**I. Temporomandibular Disorders: The Habitual Chewing Side Syndrome (HCSS)**

This study showed outcomes' correlation: TMD-pain side, the habitual chewing side, increased condylar path, and flatter lateral anterior dental guidance on same side. This statistical correlation allows us to hypothesize that the habitual chewing side could be a contributing factor to temporomandibular disorders. Consequently, seems reasonable to propose a specific etiological taxonomy, based on a plausibly etiological diagnosis, the Habitual Chewing Side Syndrome, which is characterized

by habitual chewing, a steeper condylar path, and flatter lateral anterior guidance on the affected side. "Our" diagnostic approach brings the possibility for treatment planning of the patients.

*Chewing function*

There are no validated tests to assess chewing function. Clinical tests generally fail to establish chewing function retrospectively. The interview, (Shinagawa *et al.*, 2003) which attempted to elicit information about unconscious function, was sometimes unsuccessful. Because the chewing function seems to influence the alteration, remodeling, and development of the stomatognathic structures, (Poikela *et al.*, 1997; Hinton, 1981) in this study, a particular effort was made to analyze it carefully by implementing several tests.

The unilateral chewing phenomenon has been reported previously (Szentpétery *et al.*, 1987, Reinhardt *et al.*2006). Unfortunately, in those studies, the authors did not report whether the side used to chew was associated with the affected side; moreover, the first of these studies included participants with missing teeth, and the second included participants with occlusal pathology. Despite these methodological differences, the present study seems to agree with those previous findings; moreover, it seems to confirm the asymmetry of joint biodynamics (Miyawaki *et al.*, 2001) and load distribution during jaw function (Hylander, 1979). The joint that performs the more extensive motion (nonworking side) is lubricated and can exchange metabolites better than the side that does not move (working side); however, only the teeth on the working side are stimulated, (Rios *et al.* 2008) so the stomatognathic structures can only benefit if both sides alternate in performing the chewing function.

Using one habitual chewing side is common in the general population. (Diernberger et al., 2008) This could explain, on one hand, the presence of damage to the TMJ in asymptomatic individuals, (Bernhardt et al., 2007) and on the other hand, the impossibility of establishing a cut-off

to identify healthy patients who are likely to be affected because of the multiplicity of causal factors and fluctuating nature of the symptoms. These seem to depend on the biodynamics of the masticatory dysfunction specific to each individual and/or psychobiological conditions (Diatchenko et al., 2005). The habitual chewing side appears to be associated with temporomandibular disorders but may not be sufficient per se to cause symptoms.

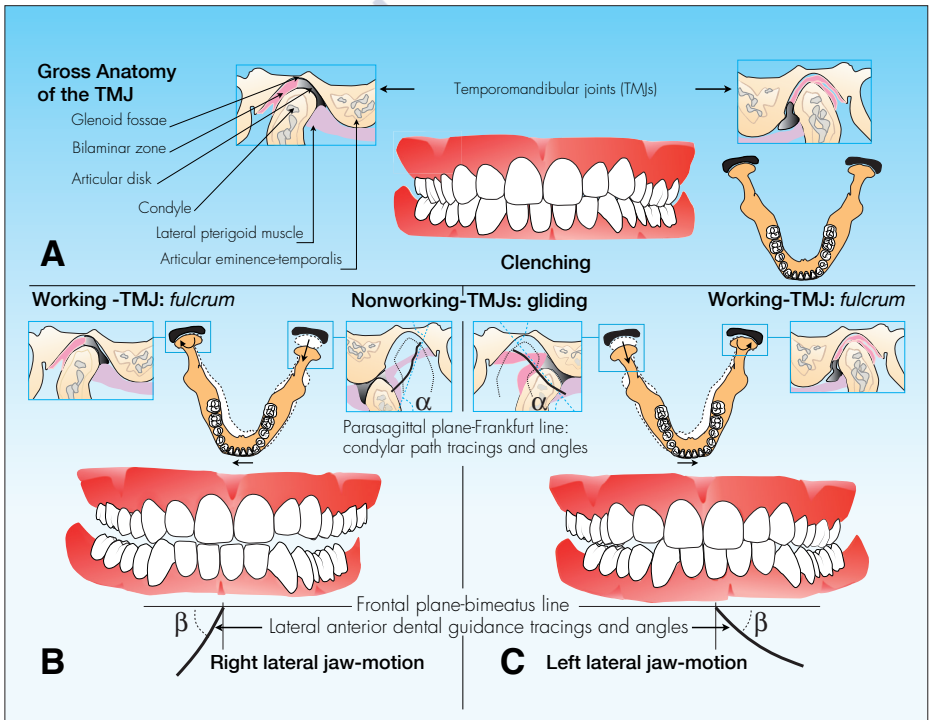


*Fig.9.- Craniomandibular relationships of a patient with left-side symptoms. A, Maximal intercuspal position. B, Right lateral jaw motion. C, Left lateral jaw motion. Left lateral jaw motion is more horizontal than right lateral jaw motion ($\alpha > \alpha'$ and/or $\beta > \beta'$).*

*Axiography*

The mechanical device used in this study is inexpensive, does not require previous casts and clutches, is not time consuming, is methodologically reproducible, (Preti *et al.*, 1982) and can be easily applied in the clinical setting.

This is the first study showing intra-individual condylar path side dimorphism in those subjects with chronic unilateral temporomandibular disorders (Figure 9). Condylar path asymmetry is probably an adaptive mechanism caused by the predominant use of one side. (Hinton, 1981) It is hypothesized that the increased condylar path (increasing eminence) causes difficulty and limits the motion of the condyle needed on the nonworking side, (Miyawaki *et al.*, 2001) which helps to perpetuate the choice of the habitual chewing side. Moreover, since the remodeling of the TMJ occurs slowly in response to biomechanical demands, the habitual chewing side is probably an associated factor rather than a consequence; though, of course, some patients avoid using one side because of pain (2 instances in this study).

*Kinesiography*

The diagnostic value of the lateral anterior guidance angles should be interpreted cautiously because some lateral jaw movements are pathologically guided by the opposite side (nonworking side interference), and in any given individual, the anterior dental anatomy may be modified because of oral rehabilitation, orthodontics, or tooth loosening).

The side exhibiting the temporomandibular disorder also shows a flatter lateral anterior guidance angle. A clinical association was previously demonstrated between a flatter lateral anterior guidance angle and temporomandibular disorders in asymptomatic patients, suggesting that flat lateral anterior guidance angles do not sufficiently protect the

ipsilateral TMJ (Ferrario *et al.*, 1996). This study provides the basis of a different explanation for this association by suggesting that the symptoms are a consequence of the biodynamics, resulting from the use of one habitual chewing side. Moreover, the higher range values and SD in the present study suggest higher intraindividual variability in lateral anterior guidance angles (range 34 to 72 degrees with intra-individual differences reaching up to 25 degrees), which, in turn, suggests severe masticatory dysfunction in chronic symptomatic unilateral TMD patients.

***Pathophysiological and Etiopathogenetic Considerations***

There are 2 distinct features of the habitual chewing side: increased masseter activity and reduced TMJ motion.

Because the masseters are responsible for TMJ loading, (Koolstra *et al.*, 1998) mainly on the nonworking side, (Hylander, 1979) the TMJ of the habitual chewing side could be overloaded when acting as the nonworking side (when the patient uses the non-habitual chewing side); moreover, the chronic reduction in condylar motion could suddenly change and perform a larger trajectory. (Miyawaki *et al.*, 2001) These alterations in biomechanics could lead to overloading of the TMJ and consequent internal damage and/or pain.

This study does not support the dominant effect of the CNS on the choice of the habitual chewing side (Pond *et al.*, 1986). On the contrary, the present results seem to confirm Hildebrand's assertion that the subject chooses the side where most teeth are in contact during lateral gliding (Hildebrand, 1936), and where the lateral anterior guide is more horizontal , and strongly suggest the influence of peripheral factors.

**Table 3.** Pain-intensity outcome:

| | Real Occlusal Adjustment | Placebo Occlusal Adjustment |
|---|---|---|
| Number of Participants Analyzed<br>(Units: participants) | 10 | 11 |
| Visual Analogic Scale (Carlsson, 1983) for Pain Intensity (0-10)<br>(units: units on a scale)<br>Mean ± Standard Deviation | | |
| Baseline | 6.52 ±1.84 | 4.8 ±1.99 |
| Immediately after therapy | .81 ±1.56 | 2.05 ±2.07 |
| 3 months after therapy | 2.25 ±2.68 | 3.80 ±2.94 |
| 6 months after therapy | .40 ±.97 | 4 ±2.31 |

Although the CNS influence does exist and does not change throughout life, it is likely that the CNS possesses the organization and plasticity to "decide" to chew on the side of the mouth that is better prepared, or perhaps less uncomfortable.

The flattening of the chewing side anterior guidance angle (Figure 9) could be a consequence and/or cause of the habitual chewing side. However, condylar path remodeling can only appear after a long period of altered chewing function; thus, it can only be a consequence.

Although sample size was small, the statistical differences across the trial were significant in the real treated group; thus, it is reasonably to assume that the masticatory function could contribute to TMD. Although generalization is risky, it allowed to design a study with a significantly larger sample size (110 Participants), which is currently carried out at the University Hospital of A Coruña.

This study was addressed to perform a randomized clinical trial: "Occlusal therapy for TMD-pain". The results of this study were posted at the *clinicaltrials.gov* international database, and the behavior of the primary outcome were as following:

**Table 4.** Maximum mouth opening outcome measures across the trial

| | Real Occlusal Adjustment | Placebo Occlusal Adjustment |
|---|---|---|
| Number of Participants Analyzed<br>(Units: participants) | 10 | 11 |
| Maximum Mouth Opening (mm)<br>(units: mm)<br>Mean ± Standard Deviation | | |
| Baseline | 41.6 ± 8.26 | 42.36 ± 10.55 |
| Immediately after therapy | 45.50 ± 7.89 | 45.07 ± 10.61 |
| 3 months after therapy | 47.10 ± 5.26 | 41.27 ± 11.31 |
| 6 months after therapy | 49.20 ± 7.28 | 41.73 ± 10.34 |

## II. A. Surface EMG activity of masticatory muscles

Masticatory muscles may show pain as a component of TMD and can be at the same time a contributor of these disorders. Probably TMJs loads are a factor of the TMD. Loads on the TMJs and teeth during clenching, functional and parafunctional activities are generated by the masticatory muscles. Muscle activity should ideally be minimal and sufficient to maintain the jaw properly positioned during active rest while presenting correct activity to perform the required functions, mainly chewing. However this ideal behavior can be altered. Classically a "vicious pathogenic circle " was invoked to explain an increased muscle activity during resting, but at this time it is not considered as such.

Due to the noise inherent to sEMG, a special effort was made to obtain clean and reproducible standard records (Merletti, 1999). Approximately 20% of the electrodes required careful relocation after new degreased, dry, jelly, and electrode fixation.

### *Data reliability*

The reproducibility was assessed in pain-free subjects to avoid possible interferences due to the patient's therapy, and was assessed by ICC. The results obtained regarding reproducibility were similar to those reported by Castroflorio *et al.* (2006).

### *EMG activity in pain-free and unilateral TMD-pain patients (Cram, 2004)*

The existence of a link between clench-EMG activity and chronic TMD is still being discussed (Lauriti et al., 2013; Manfredini et al., 2013). Several studies have shown that in clenching tasks, greater muscle activity involves greater bite-force, generated by the elevator muscles, and greater TMJ and/or tooth row loads (Hidaka *et al.*, 1999; Van Eijden *et al.*, 1993; Erhardson *et al.*, 1993; Wood, 1987; Van Spronsen *et al.*, 1992).

In agreement with other studies (Helkimo *et al.*, 1975; Fogle and Glaros, 1995), our findings showed low overall muscle activity in unilateral TMD patients ($p$=0.027, Table 1), which would suggest that a lower bite-force could be expected.

Though Molin (1972) reported no differences in bite-force between affected and non-affected sides, our findings revealed differences between muscle activity on either side, i.e., activity was lower on the affected side, which would suggest less load intensity on the affected side. The discrepancy may be due to the fact that Molin registered biting forces exerted with the mandible in the habitual closing path and the teeth about 4 mm below the intercuspal position, whereas in our study EMG was registered with clenching in the maximal intercuspal position.

In spite of alterations in the neuromuscular system, no significant differences in clenching between patients with TMD and healthy controls have been reported (Naeije et al., 1989; Nielsen *et al.*, 1990). These observations are in disagreement with our findings, which can probably be explained in terms of differences in methodology; bilateral and TMD pain patients triggered by palpation were included and were not homogenized for age, gender, laterality, or occlusion.

Apparently, the right side TMD patients performed worse tan the left side TMD ones. Although our work cannot provide a direct explanation for this particular fact, it is tempting to speculate that the hemispheric dominance influence may play some role here (i.e., asymmetry of anatomic efferences from the central motor areas and tendency to develop one preferred chewing side). It deserves future research.

***Biomechanical considerations***

The question that remain to be answered is precisely how much of the generated loads are directed to the teeth and to the TMJ. Each subject may exert slightly different bite-forces and consequently tooth and/or

TMJ loads in different clenching tasks, which may explain the variations in the intra-session EMG values, though they were not significantly different.

On the other hand, intrasession records avoid confounders such as different electrode location, differences between sides, and others. From the statistical point of view it is more correct to use the intrasession mean values. However, from a clinical point of view it seems easier to use a single record. We performed comparisons using one of the three records and similar results were found. In addition, the comparisons using non-parametric tests showed very similar significance. Thus, probably we can assume that it is enough to perform just one adequate, not-noised record by subject and session, which may be very important regarding the time and costs needed for EMG studies, particularly for large samples.

Clenching is a complex task and the biomechanism is not fully understood yet. In all likelihood, there is an ideal situation in which clenching in the maximal intercuspal position (MIP) is balanced or coincident with centric occlusion (Academy of Prosthodontics, 2005), and it is plausible to believe that the loads are transmitted on the tooth-row. From a clinical point of view, this situation has only been observed in one non-pain subject. The direction of muscle forces is as important as force intensity and the location of muscle insertion points. A primary objective is to minimize TMJ loads by distributing them on the pairs of dental molars that are designed to receive the force in order to protect the TMJs. The temporalis muscles contribute to positioning and elevation of the jaw, but cannot generate an increase in TMJ loads, in particular, transdisc ones. The masseter muscles, nevertheless, stronger and more effective than temporalis muscles as they are shorter and closer to the tooth row, can produce a force that increase TMJ loading (Koolstra *et al.*, 1988a; 1988b; Van Spronsen *et al.*, 1996), that probably happens when the jaw condyle is anteriorly displaced due to deflective occlusal contacts (Academy of Prosthodontics, 2005). In all likelihood, this would explain

why patients exhibited less masseter muscle activity during clenching, particularly on the pain side masseter, which is, in accordance with previous reports (Lund *et al.*, 1991; Nickel *et al.*, 2003), an effective protective mechanism for damaged TMJs. The specific recruitment of the masseter muscle appears to be the result of descending central modulation subsequent to nociceptive stimuli of the affected TMJ, and/or myofascial, and/or periodontal nociceptors (Sessle *et al.*, 2000a). In contrast, the non-pain side temporalis was the relatively most active jaw muscle in unilateral TMD patients, and tended to reduce the compression of the affected TMJ as well as generating a tendency to rotate the mandible, producing a fulcrum in the healthy TMJ so that the contralateral jaw condyle (of the pain side) can advance, and avoid the compression of the bilaminar zone.

In short, muscle forces are directed to minimize joint loads and muscle efforts, indicating that it is a normal protective adjustment. This study showed the capacity of the masticatory apparatus to modulate muscle recruitment, thus reducing TMJ and/or tooth row loads on the pain-side by generating less activity on the ipsilateral masseter. This unilateral reduction in temporalis and masseter activity is consistent with a conscious or subconscious effort to reduce joint loading on the pain side. This is a specific protective functional adaptation of the neuromuscular system due to nociceptive input.

### II.B "Surface raw electromyography has a moderate discriminatory capacity for differentiating between healthy individuals and those with TMD: A diagnostic study."

When rLT and rACTIVITY where considered as a linear combination, the AUC reached a value of 0.742 (95% CI 0.783–0.934), offering considerable discriminatory capacity. This helpful combination has the disadvantage that it is necessary to have the values of these two variables

and the implementation of a model that is required for computing the AUC of this combination, which cannot be obtained directly from the sum of both AUCs.

Checking the linearity in diagnostic variable-outcome relationships is important because, if we incorrectly assume a linear relationship, erroneous conclusions in clinical practice can be drawn. In addition, the use of statistical methods that make for greater flexibility (for instance, GAM) can optimize the classificatory capacity of a potential diagnostic variable with the ROC analysis (Metz, 1978; Hastie and Tibshirani, 1990; Hin et al., 1999; Wood, 2006; Lopez-Raton and Rodríguez-Alvarez, 2012). For example, with regard to the rLT, we had not used the GAM transformation; the AUC value would have been 0.52, which does not indicate a capacity to discriminate between those with TMD and those without. However, by transforming the rLT values, this variable showed a statistically significant ability to discriminate between the two groups. Moreover, if we estimate the GAM and predict outcomes by using the same dataset, the AUC value may be overestimated, that is, the prediction. The discrimination is better if the estimates are applied on the same dataset with which the model was made. The predictions are more adapted to the observed data. To solve this problem, bootstrap validation techniques were used (Steyerberg, 2008), whereby different bootstrap samples are used to estimate the model and its predictions. When this validation was performed, the capacity to discriminate decreased in all cases (for all variables) because the variability of the model was taken into account and the confidence intervals were wider. For instance, for the same variable rLT before the bootstrap validation, the AUC was 0.746 (95% CI 0.645–0.847) and after the validation, although remaining statistically significant, it decreased to 0.66 (95% CI 0.605–0.871).

Regarding the comparison between our and other reported results, this study, using raw (Santana-Mora *et al.*, 2009) or normalized (Visser et al., 1995; Tartaglia *et al.*, 2011; De Felício *et al.*, 2012) data, seems to

confirm previous information that some statistical differences in sEMG activity exist during clenching between the TMD and the healthy groups. The moderate discriminatory capacity for differentiating between healthy individuals and those with TMD shown in this study highlights the importance of sEMG studies as a complementary method for the diagnosis or for the differential diagnosis of TMD. This only moderate, not high, discriminatory capacity can be explained by the variability of the sEMG data, the fluctuation of symptoms (De Leeuw and Klasser, 2013), the heterogeneity of the TMD group, and the possible subclinical TMDs (Bernhardt *et al.*, 2007) of "healthy" participants. To gather information about this important issue, future research should include really healthy participants (up to 20% of the general population) and should include asymptomatic with perfect anatomic, dynamic, and functional symmetry.

However, these results differ from those of other similar studies (Rugh and Montgomery, 1987; Glaros *et al.*, 1997), where statistically significant differences in EMG activity between TMD and asymptomatic groups at rest have been detected. However, as those authors used parametric tests for comparisons, some concerns have arisen, and the results should be interpreted cautiously.

There is little support for the use of resting sEMG data in accurately separating TMD patients from healthy individuals (Glaros *et al.*, 1997). In clinical practice, the optimal cutoff points were often determined as the mean plus several (usually two) standard deviations of the observed results in a non-diseased simple (Richardson *et al.*, 1983). For example, some authors have determined the optimal cutoff points to be +1.00SD, +1.64SD and +2.00SD above the means of the control group, implying cutoff points at the corresponding 84th, 95th, and 97.7th percentiles.

These approaches automatically achieve specificity equal to 84%, 95%, and 97% (Barajas-Rojas *et al.*, 1993). However, these results are only

valid if the diagnostic variable follows a normal distribution. Moreover, some authors have pointed out that such a method for computing the optimal cutoff point without indicating the sensitivity measure cannot reflect the best cutoff point for discriminating between diseased and healthy populations with a specific accuracy (Greiner and Böhning, 1994).

There are several methods for selecting the optimal cutoff point in diagnostic tests. In the present study, we have considered two methods for computing the optimal cutoff point, namely, the method based on the Youden index and the sensitivity-specificity equality criterion, because these are well known and widely used in clinical practice (Youden, 1950; Aoki *et al.*, 1997; Shapiro, 1999; Greiner and Böhning, 1994; Greiner *et al.*, 2000). The method based on the Youden index computes the cutoff point that maximizes the difference between sensitivity and 1-specificity (false positive fraction).

The other criterion selects the cutoff point in which sensitivity (true positive fraction) and specificity (true negative fraction) are practically equal. These two methods assign the same weight to the two types of incorrect diagnostic classifications, because we consider that, in this case, not detecting an asymptomatic individual or not detecting an individual with TMD has more or less the same importance. However, false positive and false negative decisions can have different implications and different costs for both misclassifications could be considered when the optimal cut point is computed. Both methods provided similar cutoff points at rest, but greater differences in the optimal cutoff points were detected between the two methods when the individual clenched.

Glaros *et al.* (1997) obtained the optimal rLT value of 5.52 with a specificity of 84%, that is, they selected the optimal cutoff point (the cutoff point that "best" discriminates between both groups) as the value

+1.00SD. In our study, this value is included in the optimal interval (3.030, 22.579) obtained using the Youden index method, which achieves a sensitivity value of 55% and a specificity value of 84%.

The results related to the optimal cutoff point in terms of the percentage of correct classification suggest that the cutoff point of the rLT is the most accurate in discriminating between individuals with and without TMD, although the percentage of correct classification was similar for all diagnostic variables. As the optimal value increases, specificity increases and sensitivity decreases, that is, the capacity to detect an individual with TMD is lower.

Future research could elucidate the influence of hemispheric dominance. Moreover, the discrimination of the muscular recruitment in individuals with right and left TMD could be investigated in order to elucidate the etiology of this chronic illness.

**III. Incisal loads vs. sEMG activity of jaw-closers**

This study shows that incisal biting is a complex task in which the intensity of the bite forces influences muscular co-activation, and reveals a significant positive correlation between effective incisal loads and the magnitude of the sEMG activity of the masseter muscles during mean, but not during submaximal, voluntary biting. Moreover, while during mean effort both the masseter and temporalis muscles are co-activated, during submaximal effort a significant predominance of the masseter pair was recorded. Based on the model's predictions (Tanaka *et al.*, 1994; Korioth and Hannam, 1994; del Palomar *et al.*, 2008). Our findings suggest that the stomatognathic system (Academy of Prosthodontics, 2005) adjusts the forces to minimize TMJ loading during mean, but not during submaximal, symmetrical incisal biting; during submaximal incisal forces from the masseter muscles are predominant, although probably forces are directed to TMJs.

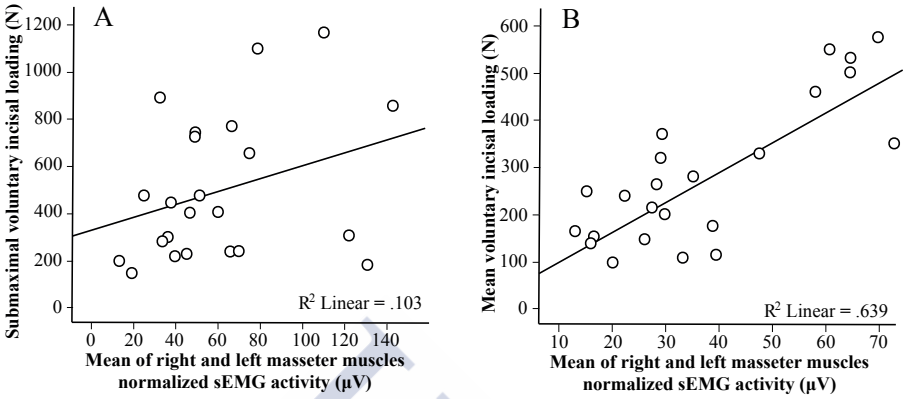


***Fig. 10.-*** *Plots of incisal loading (N) and sEMG activity (µV). A, There are no correlation between these outcomes during submaximal incisal loading; B, however, a significant linear correlation was observed between the magnitude of sEMG activity of the masseter muscles and the incisal loads of mean intensity.*

### *Methodological aspects; bias control*

Although our sample was relatively small it was homogeneous and comprised only healthy young people. All recordings, outcome assessments and statistical analyses were performed in a double-blind manner (Elwood, 2007).

A calibrated load-cell device, one of the purposes of which was to reduce as much as possible the interincisal distance (8-10 mm), and the use of a semi-rigid soft cover (latex) allowed us to apply consistent incisal loads with minimal discomfort (Arima *et al.*, 2013; Serra and Manns, 2013). The sEMG method proved to be highly reliable (Santana-Mora *et al.*, 2009).

*Characteristic muscular activity during assessed tasks*

TMJ loads depends on the position where the forces are applied (TMJ loads increases as bite is done more anteriorly (Koolstra *et al.*, 1988b) and are reduced while biting on the posterior teeth) and muscular co-activation; we performed a study of the sEMG activity and the effective charges (Santana-Mora *et al.*, 2014). Alluding only to one already published aspect, we demonstrated that the same task, in this case incisal biting, is not simple and with a constant response, as has been reported (Tanaka *et al.*,1994), it is a complex task that is dependent of the intensity of the effective force exerted and the masticatory system seems to apply low forces in order to protect the system (co-activation of elevators), probably trying to minimize TMJs loads, but for submaximal effort where are required forces (mainly of masseter muscles, responsible for TMJ loads increase increasing) primarily aimed to obtain effective loads, allowing us to infer that the TMJ-loads increases and can be harmful if held.

This study, based on the model's predictions (Tanaka *et al.*, 1994; Korioth and Hannam, 1994; del Palomar *et al.*, 2008), provides indirect evidence of potential harmfulness of strong incisal biting, and partially questions the contributions of Tanaka *et al.*, 1994 where they assumed that the incisal bite is a simple task that requires a unique and constant co-activation, when it seems to be a very complex task that varies proportionally, qualitatively or also quantitatively according to the objective of promoting incisal forces.

The assumptions of this study are consistent with those used in a previous study showing larger compressive stresses in the TMJs during clenching (Tanaka *et al.*, 1994). During clenching, forces generated by jaw muscles are directed to the tooth row, including the molars that are positioned near the main jaw elevators and thus receive greater loads than teeth placed anteriorly. In this study we assessed incisal biting when the remaining teeth are not in contact; thus, loads are concentrated at the incisal point, where they are directly measured with a load-transducer, and at the TMJs where they were not measured but only reasonably predicted, based on

the suggested assumptions. Although sEMG activity does not accurately estimate muscle forces, since there was a positive correlation between sEMG and load, it can be reasonably to predict that TMJ load increases when sEMG increases, as does incisal loads.

Muscular behavior during incisal biting is, in our opinion, paradoxical because the temporalis muscles may be important in performing incisal biting to avoid TMJ loading, yet these muscles are less active than the masseters. Perhaps the temporalis, as the main positioning muscles, are less efficient in producing effective forces, or perhaps their activity tends to retrude the mandible (or both). Thus, the masseters are the principal contributors to effective incisal loading, depending on TMJ loading. The findings of this study are in agreement with those detailed in a previous report (Santana-Mora *et al.*, 2009) showing no differences among the four sites during clenching in healthy controls, although they disagree with other reports (Farella *et al.*, 2008) indicating significant predominance of the temporalis muscles over the masseters during clenching, which could suggest the presence of subclinical TMD (Santana-Mora *et al.*, 2009).

The masseteric sEMG activity was significantly lower during submaximal or during mean incisal loading than during clenching in the maximal intercuspal position. This reduced activity, even during submaximal effort, suggests control by the CNS, which receives information, not from the Golgi tendon organs (because the muscular forces are less than in clenching), but from the nerve endings of the TMJ or the periodontal ligaments of the incisors (Erkelens and Bosman, 1985; Bakke *et al.*, 1992; Sowman and Türker, 2008).

These biomechanical properties have implications regarding the position of the incisors (Fig. 11.A). If the molars are near the insertion point of the masseters, then the incisors are displaced forward, which requires a biomechanical type Class III lever (Fig. 11.B). Because there are no muscles to distract the posterior portion of the mandible, the condyles act

as fulcrums (Dawson, 1995), and because the condyles are nearer to the masseters' insertion point than the incisors, the forces generated by the masseters are higher at the condyles than at the incisors. Even considering that the most active part of the masseter muscles is their anterior area (Hannam and McMillan, 1994), the distance between this area and the condyle is approximately half the distance between the incisors and the masseters. Although TMJ-loads were not measured in this experiment, and other forces can act, it is plausible to assume based on previous studies (Tanaka *et al.*, 1994, Korioth and Hannan, 1994), that forces generated by the masseter pair could be distributed such that a higher proportion acts on the TMJs than on the incisal edges. Similar activity was recorded for the muscles of both sides; thus, each TMJ could be loaded with similar magnitude on each side. These expected forces were significantly higher than those recorded in the macaque *Macaca Arctoides* (Brehnan *et al.*, 1981).

***Submaximal versus mean (50%) incisal loading***

This study partially agrees with previous reports showing higher activity of the masseter muscles than the temporalis during submaximal incisal biting (Throckmorton *et al.*, 1990; Farella *et al.*, 2008). During submaximal incisal loading, the masseter muscles are the most active (Table 1, Fig. 2), being significantly less active than during submaximal clenching. A plot of the correlation between submaximal incisal forces and sEMG activity of the masseter muscles (Fig. 4A) showed no linear correlation (Pearson Correlation = 0.314; $p = 0.145$), indicating that either each participant uses his or her jaw elevators in a different way or that the muscular activity shows individual differences in capacity to generate effective forces.

However, we found no differences in normalized sEMG activity among the four muscles during mean-intensity incisal loading; the masseter pair of muscles showed a linear correlation with recorded mean incisal loads (Pearson Correlation = 0.918; $p < 0.001$; Fig. 4B), while the temporalis pair did not (Pearson Correlation = 0.196; $p = 0.382$).

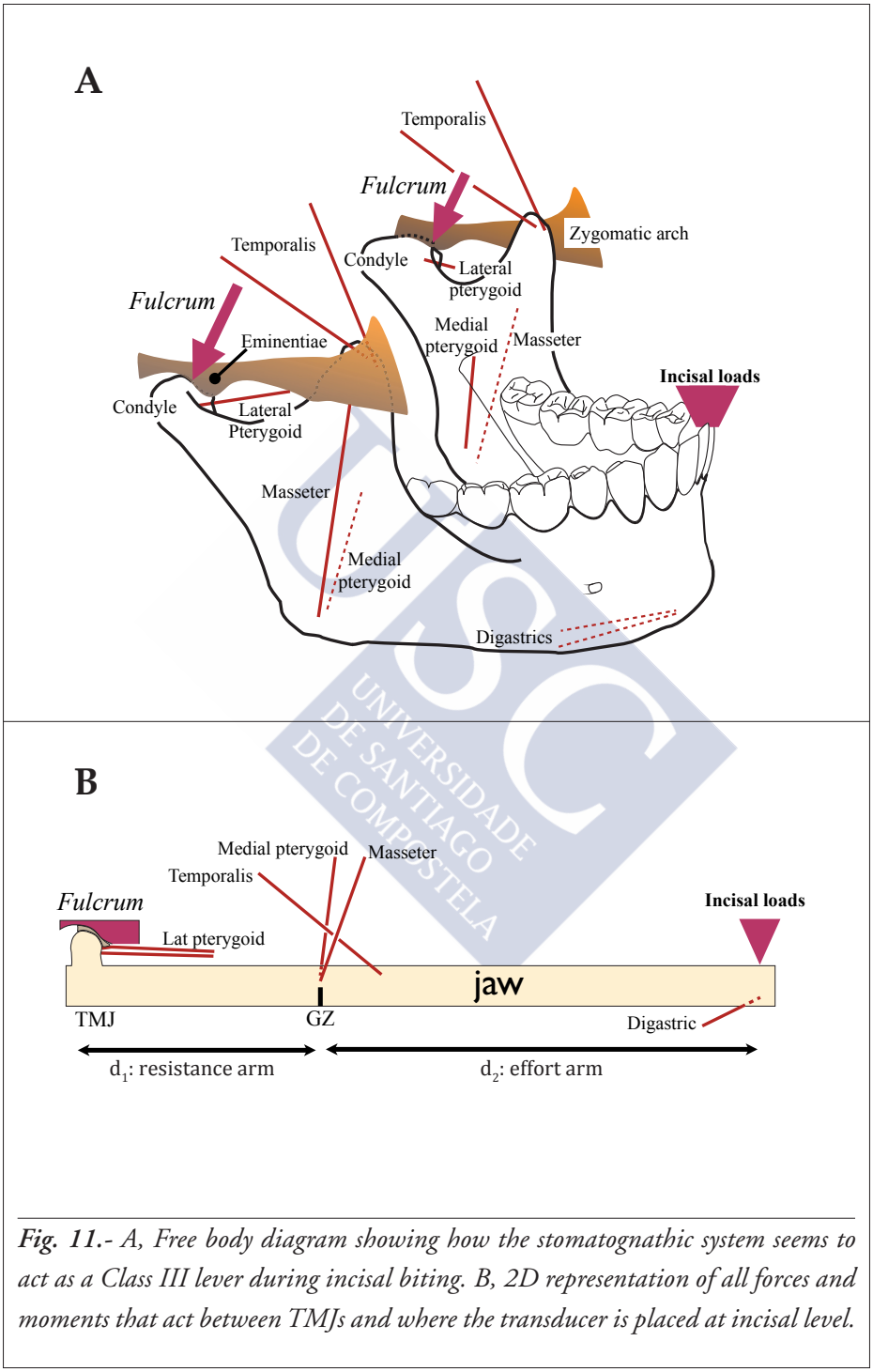


***Fig. 11.***- *A, Free body diagram showing how the stomatognathic system seems to act as a Class III lever during incisal biting. B, 2D representation of all forces and moments that act between TMJs and where the transducer is placed at incisal level.*

Thus, the magnitude sEMG activity of the masseter muscle is consistently in a linear relationship with effective incisal loads during mean effort and consequently should be considered the main muscle responsible (with respect to the temporalis) for this task, although activation of the temporalis pair suggests some degree of synergy and probably contributes (in different proportions depending on the individual) to the generation of incisal loads.

In summary, submaximal forces require the highest masseter activity while small forces produce lower activity, more evenly distributed increases in the activity of all four muscles. Thus, considering that the masseter muscles are the main muscles responsible for TMJ loads (Koolstra *et al.*, 1988a, 1988b), the task that significantly increases TMJ loading seems to be submaximal but not mean incisal bite forces.

This study proposes a new concept, the Habitual Chewing Side Syndrome that can replace the classic non-specific, symptoms describer: Temporomandibular joint pain-dysfunction syndrome. Secondly, unlike the universally accepted concept "patient with TMD" our study suggests that the (most common) unilateral TMD entity should be considered and exhibits a characteristic EMG behavior and mirror to each affected side, right or left; also shows that the raw sEMG has a moderate capacity to discriminate between healthy subjects and patients with TMD, which provides useful methodological information for other researchers in the field of sEMG.

Finally, our research shows that the concept of that the incisal bite is a task with a given sEMG activity should be reviewed, because it seems to be more complex: muscle co-activation is related to the force exerted, remaining a balanced activity of the four elevator muscles during incisal loads of medium intensity, but along submaximal voluntary effort the main activation of the masseter allow us to infer overloads of the TMJ.

These issues deserve further investigation.

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# Conclusions

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# Conclusions

— This work strongly suggests that unilateral chronic TMD affect the habitual chewing side, which is the side with a steeper condylar path and flatter lateral anterior dental guidance. These correlations allow the proposition of a new taxonomy and denomination of the TMD, the Habitual Chewing Side Syndrome, instead of the nonspecific symptoms based "Temporomandibular joint Disorders".

— *sEMG* is useful tool for diagnostic of the habitual chewing side (so called TMD).

— Incisal bite is a complex task, showing different muscular co-activation, depending of the effective incisal loading.

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